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ASPECTS DETERMINING THE RISK OF PESTICIDES TO WILD BEES: RISK PROFILES FOR FOCAL CROPS ON THREE CONTINENTS

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ASPECTS DETERMINING THE RISK OF PESTICIDES TO WILD BEES: RISK PROFILES FOR FOCAL CROPS ON THREE CONTINENTS

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This publication provides guidance on aspects of the risk of pesticides to wild bees, as part of the GEF supported Project "Conservation and Management of Pollinators for Sustainable Agriculture, through an Ecosystem Approach" implemented in seven countries - Brazil, Ghana, India, Kenya, Nepal, Pakistan, and South Africa.

The project is coordinated by the Food and Agriculture Organization of the United Nations (FAO) with implementation support from the United Nations Environment Programme (UNEP).

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ABBREVIATIONS

-	data not available
?	possibly
a.i.	active ingredient
CCD	Colony Collapse Disorder
CBS	Statistics Netherlands
Ctgb	Board for the Registration of Plant Protection Products and Biocides (of the Netherlands)
d	day
DP	Dustable Powder
EPPO	European and Mediterranean Plant Protection Organization
EU	European Union
h	hour
IGR	Insect Growth Regulator
Km	kilometre
LD_{50}	median lethal dose
µg	microgram
µL	microlitre
mL	millilitre
m	metre
mg	milligram
min	minute
n.a.	not applicable
PCPB	Pest Control Products Board (of Kenya)
TER	Toxicity Exposure Ratio
USA	United States of America
US-EPA	United States Environmental Protection Agency
WP	Wettable Powder

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*Bumble bees (*Bombus *spp.) are one of the most important groups of crop pollinators. As with all crop pollinators, they forage as well on adjacent flowering plants.*

PREFACE

Globally, agricultural production systems are under pressure to meet multiple challenges: to sustain or increase production from the same area of land and reduce negative impacts on the environment amid uncertainties resulting from climate change. As farming systems adapt to meet these challenges, there is a growing awareness that one of agriculture's greatest assets in meeting them is nature itself: many of the ecosystem services provided by nature – such as nutrient cycling, pest regulation and pollination – directly contribute to agricultural production. The healthy functioning of these ecosystem services ensures the sustainability of agriculture as it intensifies to meet growing demands for food production.

In this context, the wise management of pesticides takes on even greater urgency. Crop losses to pests are clearly the greatest major impediment to sustaining production. Pesticides are often taken as the first line of defense against pests, yet they also impact on at least two of the key ecosystem services that sustain crop yields: natural pest control and pollination.

Sustainable production intensification is inherently knowledge-intensive rather than input-intensive, and is built on an understanding of local agro-ecology. Within every farming system, there is tremendous scope to make strategic use of inputs, and work with nature to build healthy growing environments. These decisions need to be made by farmers, based on the best available evidence that can be provided to them, with an understanding of the context in which they operate.

Often, however, ecosystem services are put at risk as a result of indiscriminate use of external inputs such as pesticides, and indeed it is well-recognized that beneficial insects such as pollinators may be heavily impacted by pesticides. Risk assessment procedures for honey bees have been well elaborated as part of pesticide evaluations, based on the guidelines of the European and Mediterranean Plant Protection Organization (EPPO). However, the registration procedures of pesticides are based on information related to only one pollinator species, the

European honey bee, and are not generally field-tested in most developing countries before the pesticides are registered. As a result, pesticides are in widespread use, whose toxicity against local pollinators has never been tested.

This document contributes significantly to understanding pesticide exposure of key crop pollinators - honey bees, but also wild bee species - through the development of risk profiles for cropping systems in Brazil, Kenya and the Netherlands. In the absence of agreed quantitative risk assessment procedures for wild bees, or honey bees in (sub-) tropical cropping systems, generic risk profiles are proposed. These provide a structured assessment of the potential risks from pesticides to bees in a given crop situation while making explicit any data and knowledge gaps. We believe this approach is an excellent basis for discussion among researchers, regulators, farmers and beekeepers on how to assess potential pesticide risks to bees and pollination in specific cropping systems. Risk profiles such as those showcased in this document can provide a qualitative evaluation of pesticide risks to bees in specific settings, and can be used to compare risks between different settings, identify gaps in information, set priorities for research, and establish priorities for risk mitigation.

In its role as coordinator and facilitator of the International Pollinators Initiative (IPI) of the United Nations Convention on Biological Diversity, FAO has established a Global Action on Pollination Services for Sustainable Agriculture. Within this Global Action, and through the implementation of a GEF/UNEP-supported project on “Conservation and Management of Pollinators for Sustainable Agriculture, through an Ecosystem Approach”, FAO and its partners in seven countries - including Brazil and Kenya - have been developing tools and guidance for conserving and managing pollination services to agriculture. Through co-financing provided by the Netherlands Ministry of Economic Affairs, Agriculture and Innovation, an additional initiative on "Knowledge management of pesticide risks to wild pollinators for sustainable food production of high-value crops" has been supported with national partners in Brazil, Kenya and the Netherlands, of which this document is one of the key outcomes.

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Cultivation of french beans in the highlands of East Africa is increasingly important for local and export markets.

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Above: *Pumpkin and marrow crops in North and South America are pollinated by specialist wild bees, called "squash bees".*
Below: *Melons, along with other cucurbit crops like pumpkin and marrows, are completely dependent on animal pollinators – such as this honey bee in Brazil – to produce fruit.*

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CHAPTER 1
INTRODUCTION

1.1 PURPOSE OF THE STUDY

It has only recently been recognized how essential pollinators are to the world's ecosystems in general, and horticultural crop production specifically. The services that bees and other pollinators provide freely to agriculture have been taken for granted in the past. But as agriculture has intensified, with larger fields and greater applications of agrochemicals, populations of pollinators have shown steep declines in a number of localities. Multiple causes are indicated, amongst them the impacts of pesticides on pollinating insects.

As a contribution to identifying measures needed to counteract pollinator decline, an initial profile of the levels of risk that pollinators may be exposed to in diverse farming systems is warranted. In this publication, we have developed such a profile, and tested and modified it by its application to bees in a range of agricultural systems in Brazil, Kenya and the Netherlands. The procedure for developing risk profiles for focal crops, as well as the information derived from developing such profiles in the three countries, is presented as guidance for others who may wish to do the same. The risk profiling approach described in this report may serve in identifying research priorities for pesticide risk assessment and risk mitigation for pollinators. It can also be used, however, to identify which cropping systems are likely to expose pollinators to high pesticide-induced risks, and where risk reduction measures should therefore be taken urgently.

1.2 IMPORTANCE OF POLLINATION

Pollinators contribute greatly to food security. Effective pollination results in increased crop production, better commodity quality and greater seed production. In particular, many fruits, vegetables, edible oil crops, stimulant crops and nuts are highly dependent on animal pollination. Animal pollinators such as bees affect 35 percent of the world's crop production, increasing

outputs of 87 of the leading food crops worldwide, or 75 percent of all crops [1]. The total economic value of crop pollination worldwide has been estimated at €153 billion annually [5]. The leading pollinator-dependent crops are vegetables and fruits, representing about €50 billion each, followed by edible oil crops, stimulants (coffee, cocoa, etc.), nuts and spices; most of these are critically important for nutrient security and healthy diets.

There does not (yet) appear to be a shortage of pollinators affecting crop yields at a global scale, even though this may occur at local scales for individual crops [3]. However, over the last 45 years agriculture has become more dependent on pollinators due to a large increase in the area cultivated with pollinator-dependent crops [2]. In addition, crops with greater pollinator dependence have shown lower growth in yield and greater yield variability relative to less pollinator-dependent crops [4]. The global capacity to provide sufficient pollination services may be stressed, and more pronouncedly in the developing world than in the developed world [110].

In the three countries in our study, the economic value of pollination services is undeniably important. The value of Brazilian export of eight important agricultural commodities dependent on pollinators is estimated at €7 billion annually [6]. The annual economic value of insect pollination in East Africa has been estimated at €900 million [7]. In the Kenyan district of Kakamega alone, 40 percent of crop production (€2.4 million) could be attributed to bee pollination. In neighbouring Uganda, annual pollination services were estimated to be worth about €370 million, compared to a total economic crop value of €870 million [8]. The value of animal pollination for Dutch agriculture is estimated at €1 billion annually [9].

1.3 ROLE OF WILD POLLINATORS

Honey bees and bumblebees, often managed, are among the most important pollinators of crops in both temperate and tropical areas [98]. However, wild bees (both social and solitary species) are also essential for pollination of many crops, especially in the tropics and in cropping systems which include a high diversity of crops within the same area. In some cases, wild bees complement pollination done by honey bees, but for many tropical crops wild bees are the principal or only pollinator [1, 10, 11, 47].

For example, in the Kenyan district of Kakamega, 99 percent of the crop production value attributable to pollination was provided by wild bees [7]. The main effective pollinators of passion fruit (*Passiflora edulis*) in Brazil are carpenter bees of the genus *Xylocopa* [58]. The importance of wild pollinators was recently also underlined in oilseed rape and other crops in Europe [12, 103] and *Brassica* in New Zealand [104].

1.4 THREATS TO POLLINATORS

There is increasing evidence that insect pollinators, both wild and managed, are in decline in many regions of the globe, with the clearest cases documented in Europe and North America [13]. Colony Collapse Disorder (CCD) of is one the most dramatic causes, among several others, of honey bee mortality [14, 108]. However, bumblebee populations and other wild bees, even though much less well studied, also show clear declines [13, 15, 16].

Various causes for this decline have been identified, including loss, fragmentation and degradation of habitats, reduction in resource diversity, pests and pathogens of pollinators, competition by introduced pollinators, climate change, reduced genetic diversity, and pesticide use – all potentially causing direct and indirect adverse effects on pollinator populations. There appears to be agreement that not one of these pressures is primarily responsible for the observed pollinator decline, but that interactions among multiple factors are likely in effect [13, 15, 17, 18, 108]. Both managed and wild pollinators face many common threats, and both are subject to significant declines [98].

Losses in wild bee diversity and numbers are particularly strong under intensive agricultural management [19]. A recent large study in winter cereals showed that insecticide use had a significant negative effect on bee species richness and abundance [105]. So far, no large honey bee losses have been reported from Africa, Australia or South America [14, 20], but increasing agricultural expansion and intensification pose a significant risk to both managed and wild pollinators on these continents [20, 21, 22]. This is illustrated by the fact that pesticide imports have increased by 38 percent in Kenya between 2003 and 2008 [23], and pesticide sales in Brazil have tripled between 2000 and 2010 [21].

1.5 PESTICIDE RISK ASSESSMENT

To address the impact that pesticides may have on pollinators several tools have been developed. These tools vary from relatively simple hazard assessments (evaluating only pesticide toxicity) to more sophisticated risk assessments (where a combination of pesticide toxicity and potential exposure to the pesticide is assessed). Since risk assessment integrates pesticide toxicity and bee exposure, it is generally considered to be more relevant for the estimation of potential impact than a hazard assessment. However, not in all cases will appropriate estimates of exposure be available, and a hazard assessment will then provide an initial indication of the likelihood of adverse effects of the pesticide to bees.

Pesticide hazard and risk assessment for bees in the EU, USA or Australia has so far focused on managed western honey bees (*Apis mellifera*) alone [24, 25, 26, 86]. However, honey bees may

have different intrinsic susceptibility to pesticides than other bees. They may also be exposed in a different manner due to variations in behaviour and life history, and bee populations may respond in varied ways to pesticides because of differing natural history and population dynamics. Consequently, the pesticide risk assessment procedures currently applied for managed honey bees are not necessarily directly applicable to other bees. Only recently have pesticide risk assessment methods for bees other than honey bees received more attention [27, 112], but no clear consensus on risk assessment procedures has yet been established.

1.6 PESTICIDE RISK PROFILING

In order to conduct a proper risk assessment of pesticides to bees, information is needed in three areas: (i) the toxicity of the pesticide; (ii) the probability of bee exposure to that pesticide; and (iii) the natural history and population dynamics of the bee species in question.

Pesticide **toxicity** data have mainly been generated for the western honey bee (*Apis mellifera*), but much less so for other *Apis* species or non-*Apis* bees (either native or managed). Increasingly, however, toxicity tests are being done with bees other than *Apis mellifera*, although not all of these have found their way to the international published literature.

The probability and degree of **exposure** to pesticides depends on cropping and pesticide application practices, pesticide properties, attractiveness of the crop to bees, and certain aspects of bee biology (in particular phenology and behaviour). Data on these aspects of exposure, for a given crop in a given country or region, may be available from agricultural extension services, pesticide registration authorities, bee experts, agronomists and environmental scientists.

Finally, the **natural history and population dynamics** of the bee species will determine how an observed effect of the pesticide (either lethal or sublethal) will affect long-term survival of the population. This includes such factors as the population size of the bee species at the time it is exposed to the pesticide, its population growth rate, and the migration capacity of the bee species, among others.

In this assessment, we have attempted to collect information relevant to pesticide risk for (primarily wild) bees that are important on a limited number of focal crops. Because this is not a conventional risk assessment, we use the term “risk profile” to qualify our assessment. Initially, such risk profiling aims to better identify gaps in our present knowledge that requires further research. In the longer term, the established risk profiles may provide inputs for risk assessment models that consider wild and non-*Apis* managed bees, which may lead to recommendations for specific risk mitigation measures.

CHAPTER 2
METHODOLOGY

2.1 FOCAL CROPS

A limited number of economically important focal crops were chosen for developing a risk profile (Table 1). Focal crops were selected because of their dependence on pollination by wild and/or managed bees, and/or because wild bees were known to be active in these crops.

Cucurbits, such as melon *(Cucumis melo)*, watermelon *(Citrillus lanatus)* and squash *(Cucurbita moscata)* are highly dependent on bee pollination and reduced production by more than 90 percent can be expected when lacking animal pollination [1]. Both honey bees and other bees are important pollinators.

Highland coffee *(Coffea arabica)* is self-pollinating, but both honey bees and other bees have been shown to increase yields by over 50 percent [1, 28, 47]. Lowland coffee *(Coffea canephora)* is self-incompatible, and animal pollination is of great importance for berry production [1, 29].

Tomato *(Solanum lycopersicum)* is self-compatible, but requires wind- or insect-mediated vibration of the flower anthers for pollination (e.g. by buzz pollination) [1]. Bumblebees, some stingless bees and some solitary bees are good buzz pollinators [91].

French beans *(Phaseolus vulgaris)* are self-compatible, but increases of up to 10 percent in yield may be possible with optimal pollination. Furthermore, pollination of French beans may improve the quality and uniformity of seed yield [97]. The production of apple *(Malus domestica)* greatly depends on insect pollination, and honey bees, bumblebees and solitary bees all have been found to increase fruit yields [1].

Table 1

FOCAL CROPS FOR WHICH PESTICIDE RISK FACTORS WERE ASSESSED

COUNTRY	BRAZIL	KENYA	NETHERLANDS
Focal crops	Melon Tomato	Coffee Cucurbits (watermelon and squash) French beans Tomato	Apple Tomato (greenhouse)

2.2 RISK FACTORS

A preliminary list of main factors considered to potentially influence pesticide risk to bees was established. Although the list was established after considerable review, it is not necessarily exhaustive (Table 2).

Factors may have different possible effects on pesticide risk to bees. In some cases, a clear correlation between a given factor and an increase or reduction of risk can be assumed. In other cases this relationship is less clear and requires more detailed information on bee biology or the cropping situation.

On the basis of this list, a simple questionnaire was designed to collect information on risk factors for focal crops in the three participating countries. Annex 1 presents the most recent version of the questionnaire, which was updated using the insights resulting from the study presented here. Life history and population dynamics factors were originally not included in the survey, but later added based on literature data.

Table 2

PESTICIDE RISK FACTORS AND THEIR POSSIBLE EFFECTS ON BEES

RISK FACTOR	POSSIBLE EFFECT ON THE RISKS OF THE PESTICIDE TO BEES
EXPOSURE – CROP FACTORS	
Surface area under crop: - overall size - patchiness	 Larger surface area under the specific crop ➔ higher exposure risk Lower fraction of the crop in the overall area ➔ lower exposure risk
Period(s) in the growing season when pesticides are applied to the crop	(Determinant for factors below)
Period(s) in the year when the crop flowers	If overlap between flowering of crop and pesticide applications ➔ higher exposure risk
Period(s) in the year when bees are foraging or collecting nesting materials	If overlap between bee activity in crop and pesticide applications ➔ higher exposure risk
Period(s) when weeds are flowering in the crop which may be attractive to wild bees	If overlap between flowering of weeds and pesticide applications ➔ higher exposure risk
Crop has extrafloral nectaries	If extrafloral nectaries present in crop ➔ higher exposure risk
Crop is regularly infested with honeydew producing insects	If honeydew producing insects present in crop ➔ higher exposure risk
Drinking water is available in the crop	If drinking water in the crop ➔ higher exposure risk
EXPOSURE – BEE BIOLOGY FACTORS	
Location of nest in relation to crop field	In-field and field-border nests ➔ higher exposure risk Off-field nests ➔ lower exposure risk (depending on distance)
Bee foraging range	If in-field and field border nests: shorter foraging range ➔ higher exposure risk If off-field nests ➔ risk depends on distance between nest and sprayed field
Time spent foraging, or collecting nesting materials, per day ("time-out-of-nest/hive")	More hours out-of-nest/hive ➔ higher exposure risk
Period of the day when foraging or collecting nesting materials	Early/middle in the day ➔ possibly lower exposure risk (if pesticide is applied afterwards and has very low persistence) All-day/late in the day ➔ higher exposure risk
Number of days spent foraging on the crop (for an individual bee)	More days spent foraging ➔ higher exposure risk
Number of days spent foraging on the crop (for the colony)	More days spent foraging ➔ higher exposure risk

follows on the next page →

RISK FACTOR	POSSIBLE EFFECT ON THE RISKS OF THE PESTICIDE TO BEES
EXPOSURE – BEE BIOLOGY FACTORS	
Number of different nectar and pollen plant species used during crop flowering	Fewer species ➔ higher exposure risk
Quantity of pollen collected per day	Higher quantity ➔ higher exposure risk
Quantity of nectar collected per day	Higher quantity ➔ higher exposure risk
Quantity of nectar consumed per day	Higher quantity ➔ higher exposure risk
Body weight	Higher body weight ➔ possibly lower exposure or impact risk (also determinant for other factors)
% of pollen self-consumed	More self-consumed ➔ higher exposure risk to adult
% of pollen fed to brood	More fed to brood ➔ higher exposure risk to brood
% of nectar self-consumed	More self-consumed ➔ higher exposure risk to adult
% of nectar fed to brood	More fed to brood ➔ higher exposure risk to brood
Collective pollen and/or honey storage in the nest (social bees)	If collective pollen and honey storage ➔ lower exposure risk due to mixing, maturation and microbial action
EXPOSURE AND IMPACT – PESTICIDE USE/APPLICATION PRACTICES	
Formulation type	Some formulations types (e.g. micro-encapsulation, sugary baits, DP, WP) ➔ higher exposure risk
Pesticide is systemic	Specific exposure/impact assessment
Pesticide is an insect growth regulator (IGR)	If IGR ➔ specific impact on brood
Mode of application	Some modes of application (e.g. dusting, aerial application) ➔ higher exposure risk Some modes of application (e.g. seed/soil treatment with non-systemic pesticide; brushing) ➔ lower exposure risk
Application rate	For the same pesticide product: higher application rate ➔ higher exposure/impact risk
Application frequency	Higher application frequency ➔ higher exposure risk
Systemic pesticides are applied as soil treatment or seed treatment to a previous rotational crop	If systemic pesticides applied to a previous rotational crop ➔ possibly higher exposure risk
IMPACT AND RECOVERY – PESTICIDE PROPERTIES	
Contact LD_{50} (adult)	Lower LD_{50} ➔ higher impact (for similar exposure levels)
Oral LD_{50} (adult)	Lower LD_{50} ➔ higher impact (for similar exposure levels)
Oral LD_{50} (brood)	Lower LD_{50} ➔ higher impact (for similar exposure levels)
Foliar residual toxicity	Higher residual toxicity ➔ higher impact (for similar exposure levels) & lower likelihood of recovery after pesticide impact
IMPACT AND RECOVERY – LIFE HISTORY AND POPULATION DYNAMICS FACTORS	
Individual metabolic rate	Higher metabolic rate ➔ lower impact (increased detoxification)
Degree of sociality	High degree of sociality with one or more reproductive queens and separate foragers ➔ lower risk of impact to the population/colony because pesticide affects primarily foragers (except for Insect Growth Regulators (IGRs)
Fraction of population/colony active out of the nest/hive (social bees)	Higher fraction of population of colony active out of the nest/hive ➔ higher risk of impact for the whole population/colony
Time to reproductive age of queen/reproductive female (egg-adult)	Shorter development time ➔ lower exposure risk (if development partly overlaps with flowering)
Number of offspring per queen/reproductive female	Greater number of offspring ➔ greater likelihood of population recovery after pesticide impact
Number of generations per year	Greater number of generations per year ➔ greater likelihood of population recovery after pesticide impact
Population growth rate [note: as product of previous 3 factors]	Higher population growth rate ➔ greater likelihood of population recovery after pesticide impact
Number of swarms per colony or reproductive events per year	More swarms or more frequent reproduction ➔ greater likelihood of population maintenance, if swarming or reproduction occurs before pesticide impact or ➔ greater likelihood of population recovery after pesticide impact
Migration and dispersal distance	Greater dispersal distance ➔ greater likelihood of population recovery after pesticide impact (if cropping is patchy); however if migratory routes are used, possible multiple exposure to pesticide

2.3 DATA COLLECTION

The methodology used to collect, compile and evaluate the information was not identical in the three countries.

In **Brazil**, cropping and bee data were collected through discussions with crop and pollination experts and by consulting published and unpublished literature. Pesticide use information was obtained from crop experts and the pesticide registration authority (Ministério da Agricultura, Coordenação-Geral de Agrotóxicos e Afins) through the Sistema de Agrotóxicos Fitossanitários – Agrofit [30].

In **Kenya**, cropping and bee data were collected through discussions with crop and pollination experts and by consulting published and unpublished literature. Pesticide use information was obtained from crop experts and the Kenya Pest Control Products Board (PCPB) [31]. In addition, an extensive survey was carried out on pollinator knowledge and crop protection practices covering approximately 150 farmers in Machakos, Kirinyaga and Kiambu counties.

In **the Netherlands**, cropping and bee data were collected through discussions with crop and pollination experts and by consulting published and unpublished literature. Pesticide use information was obtained from Statistics Netherlands (CBS) [32].

Pesticide toxicity data for bees were collected centrally, using various databases and literature sources. For this assessment, acute LD_{50} values for the **western honey bee** (*Apis mellifera*) were obtained from a recently compiled database, drawn from multiple regulatory and non-regulatory data sources [33]. The lowest (generally 48h) LD_{50} value of both oral ingestion and contact tests, as calculated using the rules defined for the database, was used in this report. When LD_{50} values were not available in the database, the Footprint Pesticide Properties Database [34] and the Footprint Biopesticides Database [35] were consulted. Results from brood tests, or sublethal toxicity tests, have not been taken into account in the present report.

Toxicity data for bumblebees (*Bombus*) are increasingly being collected, and were recently reviewed [36]. This review was used to check whether acute LD_{50} values for bumblebees were available for the pesticides used in our focal crops. Pesticide toxicity data for bees other than *Apis mellifera* and *Bombus* are still limited. No public database appears to exist for such bees and toxicity data for other bees were therefore not included in this assessment. Pesticide types and modes of action were noted according to the Pesticide Manual [37] or the Footprint Pesticide Property Database [34].

The foliar residual toxicity is the duration that a pesticide remains toxic to bees on foliage. In the USA, foliar residual toxicity is generally assessed for pesticides with an acute $LD_{50} < 11$ µg/bee [86]. Foliar residual toxicity duration as reported by various US agricultural extension services was used in this assessment [87, 88]. Such toxicity data have been determined for the honey bee at maximum common USA application rates.

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Above: *Tomatoes in Kenya may be sprayed with insecticide to prevent damage from whiteflies.*
Below: *Increasingly, horticultural crops in Kenya are being grown under shelter, with new challenges for pest control and pollination.*

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Male bees, such as these two from Kenya (of different genera, Amegilla *and Tetralonia) sleep by clasping to vegetation during the night; they thus may be vulnerable to pesticide sprays that take place at night – often recommended as a possible mitigation measure. However, the behavior and exposure of male bees has not been assessed in this report.*

CHAPTER 3
RESULTS

3.1 PRESENCE OF BEES

The main groups of bees visiting the focal crops in the three countries are listed in Table 3.

Although the honey bee (*Apis mellifera*) is found on all three continents, the subspecies are different. In Brazil, the Africanized honey bee (hybrids between *A. m. scutellata* on the one hand and – primarily – *A. m. mellifera. A.m. ligustica, A.m. carnica and A.m. caucasia*) is predominant [38]. It has been argued, however, that in spite of the hybridization the genetic and behavioural characteristics of the African honey bee (*A. m. scutellata*) have been largely preserved [38]. In Kenya, the four subspecies present are *A. m. scutellata*, *A. m. monticola*, *A. m. litorea, and A. m. nubica* [94, 95, 96]. In the Netherlands, honey bees are mainly *A. m. mellifera* and *A. m. carnica*, and will be referred to as European honey bees below.

The main pollinator of **melon** in north-eastern Brazil is the honey bee [39], although the crop is also visited by carpenter bees (*Xylocopa*) and stingless bees (Meliponini). The honey bee is also the main pollinator of **watermelon** in Kenya, while various species of sweat bees bees (Halictidae – e.g. *Lasioglossum* spp.), carpenter bees and stingless bees (e.g. *Hypotrigona* spp.) are also observed on this crop [40, 41]. Similarly, honey bees were the most common bee pollinator found on **bottle gourd** in Kenya [42]. The importance of wild bees (in addition to honey bees) for pollination of **cucurbits** has also been noted elsewhere, e.g. in Brazil on *Cucurbita* [55], in Ghana on sponge cucumber (*Luffa aegyptiaca*) [43], and on squash/pumpkin (*Cucurbita pepo*) in the USA [44, 45].

Tomato is often considered to require buzz pollinators for effective pollination. A wide variety of bees pollinate field tomato in Brazil, including bumblebees, carpenter bees, sweat bees, stingless bees, and a long-horned bee. The last group is also being investigated as a pollinator for greenhouse tomato in Brazil [46]. Sweat bees and carpenter bees are reported as pollinators of field tomato in Kenya, but bumblebees are not naturally present in Sub-Saharan Africa. In the Netherlands, tomato is mainly grown in greenhouses, and commercially reared bumblebees (*Bombus terrestris*) are the main pollinators of this crop.

Table 3

MAIN GROUPS OF BEES VISITING THE FOCAL CROPS, AND THEIR ROLE AS POLLINATOR OF THOSE CROPS

COUNTRY	CROP	BEE GROUP/SPECIES VISITING THE CROP	
		IMPORTANT POLLINATOR	VISITOR; NOT AN IMPORTANT POLLINATOR
Brazil	Melon	*Apis mellifera* (honey bee)	*Xylocopa* (carpenter bees) *Frieseomelitta doederleini* (stingless bee)
	Tomato	*Bombus transversalis* (bumblebee) *Bombus atratus* (bumblebee) *Bombus morio* (bumblebee) *Xylocopa grisescens* (carpenter bee) *Augochlora* (sweat bees) *Exomalopsis auropilosa* (long-horned bee) *Melipona* (large stingless bees)	*Apis mellifera (*honey bee)
Kenya	Cucurbits	*Apis mellifera* (honey bee) Halictidae (sweat bees) (e.g.*Lasioglossum*)	Xylocopa (carpenter bees)
	Coffee	*Apis mellifera* (honey bee) *Patellapis* (sweat bees) *Xylocopa* (carpenter bees) *Megachile* (leafcutter bees)	
	French beans	*Xylocopa* (carpenter bees) *Megachile* (leafcutter bees)	*Apis mellifera (*honey bee)
	Tomato	*Xylocopa* (carpenter bee) *Lipotriches* (sweat bees)	*Apis mellifera* (honey bee)
Netherlands	Apple	*Apis mellifera* (honey bee) *Osmia rufa (=O. bicornis)* (red mason bee) *Bombus* (bumblebees) (mainly *B.terrestris/lucorum; B. pascuorum; B.lapidarius*)*Andrena* (sand bees)	
	Tomato	*Bombus terrestris* (bumblebee)	

French beans are self-compatible but pollinators can increase yield and seed set [97]. However, both wild bees and honey bees are regular visitors to flowers of French beans in Kenya.

Highland **coffee** in Kenya is reportedly pollinated by honey bees, sweat bees, leafcutter bees and carpenter bees [47]. These are similar pollinator groups as found in lowland coffee in neighbouring Uganda, although stingless bees were also particularly important there [29]. The importance of wild bees for pollination and subsequent quantity and quality of coffee production has been explicitly underlined for Kenya [47, 54] and for Central America [28, 48, 49].

Honey bees, sand bees (*e.g. Andrena carantonica, A. flavipes, A. haemorrhoa*), mason bees (*Osmia rufa*) and bumblebees (*e.g. Bombus pascuorum and Bombus terrestris/lucorum*) are important pollinators of **apple** in the Netherlands [50]. In a recent study, wild bees were the most frequent flower visitors (59 percent of observations), followed by honey bees (29 percent) and hover flies (12 percent) [50]. This is not limited to the Netherlands, because populations of mason bees (e.g. *O. rufa* and *O. cornuta* in Europe; *O. cornifrons* and *O. lignaria* in the USA) are released in apple

orchards because of their high efficiency of pollination [51, 52]. The sand bee *Andrena barbara* was found to be an important pollinator of apple in southwest Virginia (USA) [53].

In conclusion, in all focal crops, except melon in Brazil and tomatoes in the Netherlands, wild bees may contribute significantly to pollination. This is in addition to, or instead of, the honey bee. Furthermore, in all focal crops, the groups and/or species of bees that are regular visitors appear to be relatively well known. In many cases, important pollinators have been identified, although for some crops the role of wild bees as pollinators requires more study (e.g. *Xylocopa* and Halictidae in cucurbits and tomato in Kenya, *Andrena* in apple in the Netherlands).

3.2 RISK FACTORS

3.2.1 Exposure – crop factors

Various crop-related factors may increase bee exposure to pesticides, such as overlap between the presence of bees in the crop area and flowering of the crop or weeds, overlap between bee activity on the flowering crop and pesticide application, or the presence of extrafloral nectaries, insects producing honeydew, or drinking water in the crop area. These factors are summarized for the focal crops in Table 4.

The main factors influencing risk are probably the overlap of pesticide applications with crop flowering or with bee activity in the crop area. In all but one crop, pesticides are applied during flowering and bee activity. Only in coffee production in Kenya, pesticide applications during flowering are explicitly being avoided. This is not done to protect pollinators but because farmers do not expect any major pest that may interfere with fruit setting and they fear that pesticide spraying may harm flowering. Weeds are a major production constraint in most systems, and pollinator visits to their flowers when pesticides are being applied may constitute a route of exposure. However, only in apple in the Netherlands was an explicit risk of exposure identified of bees foraging on Dandelion flowers just before the apple flowering period.

Of the focal crops, only French beans have extrafloral nectaries. Some cucurbits also have them, but the relevant cucurbit crops in Kenya do not [99]. Most crops are regularly infested by honeydew producing insects such as aphids, whiteflies and scale insects. In all three countries these pests are controlled with insecticides, and to what extent bees will be attracted to such pests to forage honeydew requires further study. The focal crops in both Brazil and the Netherlands may contain sources of water used by bees; this was not assessed in Kenya. In general, however, bees will use nectar as the main drinking water source. In the Netherlands, bumblebees may drink (potentially contaminated) condensed water from the greenhouse walls, but generally only after the sugar water provided in the colony boxes is depleted.

Table 4

FACTORS RELATED TO CROPPING PRACTICES THAT MAY INFLUENCE THE RISK OF BEE EXPOSURE TO PESTICIDES

EXPOSURE – CROP FACTORS	BRAZIL		KENYA				NETHERLANDS	
	MELON	TOMATO	CUCURBITS	COFFEE	FRENCH BEANS	TOMATO	APPLE	TOMATO
Pesticide application overlaps with the flowering period of the crop	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes
Pesticide application overlaps with the flowering period of weeds in the crop	No	No?	No	No	No	No	Yes	No
Pesticide application in the crop overlaps with the period when bees are actively foraging or collecting nesting materials in the crop	Yes	Yes	Yes	No?	Yes	Yes	Yes	Yes
Crop has extrafloral nectaries	No	No	No	No	Yes	No	No	No
Crop is regularly infested with honeydew producing insects	Yes	Yes?	Yes	Yes	Yes	Yes	Yes	Yes
Crop may be visited by bees for collection of water	Yes	Yes	-	-	Yes	Yes	Yes	Yes
Overall likelihood of exposure	**high**	**high**	**high**	**low**	**high**	**high**	**high**	**high**

- = data not available; ? = possibly
Sources: Questionnaires of this study. For the Netherlands, also see Annex 4 for details on timing of pesticide applications.

Overall, the likelihood of bee exposure to pesticides used in the focus crops, based on crop-related aspects, can be considered high. The only exception is coffee in Kenya, where pesticides tend not to be applied in the period when bees are foraging.

3.2.2 Exposure – bee biology factors

Bee biology may affect both the risk of bee exposure to a pesticide, as well as the resulting impact. Parameters related to bee biology collected in the survey, as far as they may influence bee exposure, are summarized in Tables 5, 6 and 7. This includes the period, duration and range of foraging, nest location, and nectar and pollen consumption. In the tables, a comparison is made between the European honey bee and the other bees active in the crop. This was done because the standard risk assessment used in Europe, and to a lesser extent in North America, has been validated for the European honeybee, but not for the African subspecies or Africanized honey bee in South America.

It should be noted that many of the listed factors are highly variable for individual species, but even more so among groups of bees. For instance, foraging ranges will depend on the availability of suitable flowering plants, but are also determined by bee size. The timing of foraging may be greatly influenced by weather conditions. The quantity of pollen and nectar collected depends on the size of the colony, the size of the bees, and also on the sugar content

of the nectar. In the tables, the average, median value or range is generally shown. If country or crop-specific data were available, the aforementioned variables were listed. Otherwise, more general values for the bee group are provided, generally obtained from review articles. Sources for the data are provided in each table.

Mating behaviour and specific activities of males which may affect pesticide exposure were not assessed. Generally, male bees do not stay in a nest but are active in the field, and may a have 'roosting site', to which they return at night. Furthermore, in many bee species and groups, the males have an established mating site to which females fly, so that mating can occur. The influence of pesticide applications on such sites is in great need of study, and the implications of pesticides or pesticide residues there are potentially significant.

For **Brazil**, specific information for the Africanized honey bee was listed when available, but in some cases data of the European honey bee have been listed in Table 5. Africanized honey bees have been reported to collect greater quantities of pollen [38], but this was not quantified. On the basis of the available information on bee biology, likelihood of exposure to pesticides of Africanized honey bees is probably similar to European honey bees.

Limited information was available for the other groups of bees identified as tomato pollinators in Brazil. Bumblebees are active on the tomato crop for a similar duration (both individually as for the colony) as the honey bee. Due to the lack of information on biology of other bees, it is not possible to make clear inferences about the relative likelihood of exposure of wild bees on tomato in Brazil.

For **Kenya**, information on the African honey bee was available, but limited for *Xylocopa* (carpenter bee) and sweat bees (Halictidae). No information on relevant bee biology factors could be obtained for leafcutter bees (*Megachile*) and the sweat bee *Patellapis*. Based on the limited bee biology data available, there is no reason to expect higher pesticide exposure for *Xylocopa* than for European honey bee in Kenya, but some key factors could not be quantified. As was the case in Brazil, likelihood of exposure to pesticides of African honey bees is probably similar to European honey bees.

Based on bee biology factors, it can be inferred that sweat bees (Halictidae) on tomato in Kenya may be more exposed to pesticides than the honey bees on the same crop. This is because the nests of sweat bees are located close to the field which, in combination with the more limited foraging range, is likely to increase exposure risk. Furthermore, sweat bees are generally smaller than honey bees and individual foraging time appears longer. Finally, almost 100 percent of collected pollen is fed directly from the field to the brood, which may lead to higher pesticide exposure of offspring than is the case in honey bee or other pollen-storing bees, like stingless bees (Meliponini). When in storage, microorganisms and added nectar in pollen may accelerate breakdown of pesticides.

Table 5

FACTORS RELATED TO BEE BIOLOGY THAT MAY INFLUENCE THE RISK OF BEE EXPOSURE TO PESTICIDES – BRAZIL

EXPOSURE – BEE BIOLOGY FACTORS	MELON TOMATO	TOMATO				
	Apis mellifera (Africanized)	*Bombus*	*Xylocopa grisescens*	*Augochlora sp*	*Exomalopsis auropilosa*	*Melipona*
Location of nest in relation to crop field (approximate distance from crop field)	Outside (100 – 500 m)	Outside	Outside	Outside?	Outside	Mainly outside[1]
Average bee foraging range (maximum distance from nest)	~1500 m (10 km)	-	(12 km)	Limited?	-	500–1000 m (2100 m)
Time spent foraging or collecting nesting materials	~10–15 trips/d; 4–11 hrs/d (individual nectar forager); ~1.5 hrs/d (individual pollen forager)	Up to 10 hrs/d (colony)	~12 min/ flight & numerous flights/d	-	-	-
Period of the day when foraging or collecting nesting materials	Entire day	-	Entire day?	-	-	Morning/ entire day
Time spent foraging on the crop (for an individual bee)	5–15 d	-	-	-	-	-
Time spent foraging on the crop (for the colony)	30–60 d	30–40 d	n.a.	n.a.	n.a.	30–40 d
Quantity of pollen collected	>200–300 mg/d	15–31 mg/d	-	-	-	-
Quantity of nectar collected	250 µL/d	70 µl/ load	-	-	-	-
Quantity of pollen consumed	~6.5 mg/d (nurse bee)	-	-	-	-	-
Quantity of nectar consumed	80–320 mg/d (adult)	-	-	-	-	7-12 µL/load
Body weight	60–105 mg (worker)	40–850 mg (worker)	-	-	-	Similar to honey bee
% pollen self-consumed by adult	Limited (early adult stage)	None	-	-	-	-
% pollen fed to brood	Most; stored and transformed	100%	-	-	-	-
% nectar self-consumed by adult	Some; most stored and transformed, and consumed as honey	-	-	-	-	-
% nectar fed to brood	Most; stored and transformed and consumed as honey	-	-	-	-	-
Collective pollen and/or honey storage in the nest	Yes	Yes	Limited?	No	Limited?	Yes
Overall likelihood of exposure compared to the European honey bee	**Similar**	**Similar?**	**Unclear**	**Unclear**	**Unclear**	**Unclear**

- = data not available; ? = possibly; n.a. = not applicable; d = day; hr = hour; min = minute; mg = milligram; mL = millilitre; µL = microlitre
Sources: Questionnaire of this study, and: *Apis* [38, 74, 77, 78, 107]; *Bombus* [56, 57, 79]; *Xylocopa* [58, 59, 60, 61, 62, 63, 64]; *Augochlora* [65]; *Exomalopsis* [66]; *Melipona* [67, 68, 69, 70, 71, 72, 106]; General [73]
1 *Melipona* has been used on a limited scale to pollinate tomato in greenhouses in Brazil.

Table 6

FACTORS RELATED TO BEE BIOLOGY THAT MAY INFLUENCE THE RISK OF BEE EXPOSURE TO PESTICIDES – KENYA

EXPOSURE – BEE BIOLOGY FACTORS	COFFEE CUCURBITS FRENCH BEANS TOMATO	COFFEE CUCURBITS FRENCH BEANS TOMATO	COFFEE	FRENCH BEANS COFFEE	TOMATO CUCURBITS
	Apis mellifera scutellata	*Xylocopa*	*Patellapis*	*Megachile*	Halictidae
Location of nest in relation to crop field (approximate distance from crop field)	Inside and in field borders (50–100 m)	Outside and in field borders; fringes of woodlands/forest	-	-	Outside and in field borders; fringes of woodlands/forest
Average bee foraging range (maximum distance from nest)	~1500 m (10 km)	700–1000 m (6 km)	-	-	50–100 m
Time spent foraging or collecting nesting materials	~10–15 trips/d; 4–11 hrs/d (individual nectar forager); ~1.5 hrs/d (individual pollen forager)	1–2 hrs/d (individual bee); Median flight duration 30 min	-	-	4–10 hrs/d? (individual bee)
Period of the day when foraging or collecting nesting materials	(Early) morning/all day (on cool days)	Early and late in day	-	Mid-day	Entire day
Time spent foraging on the crop (for an individual bee)	5–15 d	Coffee: 30 d French beans: 100 d Tomato: 90 d	-	-	60 d
Time spent foraging on the crop (for the colony)	Coffee: 30 d Cucurbits: - French beans: 100 d Tomato: 90 d	n.a.	n.a.	n.a.	n.a.
Quantity of pollen collected	200–300 mg/d	-	-	-	<30 mg/d
Quantity of nectar collected	250 µL/d	-	-	-	-
Quantity of pollen consumed	~6.5 mg/d (nurse bee)	-	-	-	-
Quantity of nectar consumed	80–320 mg/d (forager)	-	-	-	-
Body weight	60–120 mg (worker)	> honey bee	-	-	3–95 mg
% pollen self-consumed by adult	Limited (early adult stage)	-	-	-	-
% pollen fed to brood	Most; stored and transformed	Up to 100%	-	-	Up to 100%
% nectar self-consumed by adult	Some; most stored and transformed, and consumed as honey	-	-	-	-
% nectar fed to brood	Most; stored and transformed and consumed as honey	-	-	-	-
Collective pollen and/or honey storage in the nest	Yes	Limited?	-	No	Limited?
Overall likelihood of exposure compared to the European honey bee	**Similar**	**Similar?**	**Unclear**	**Unclear**	**Greater?**

- = data not available; ? = possibly; n.a. = not applicable; d = day; hr = hour; min = minute; mg = milligram; mL = millilitre; µL = microlitre
Sources: Questionnaire of this study, and: *Apis* [38, 74, 75, 77, 78, 29, 40, 43, 100, 107]; *Xylocopa* [40, 43, 64, 76]; *Megachile* [29]; Halictidae [65]; General [73]

Table 7

FACTORS RELATED TO BEE BIOLOGY THAT MAY INFLUENCE THE RISK OF BEE EXPOSURE TO PESTICIDES – THE NETHERLANDS

EXPOSURE – BEE BIOLOGY FACTORS	TOMATO	APPLE			
	Bombus terrestris	*Apis mellifera mellifera*	*Osmia rufa*	*Andrena*	*Bombus*
Location of nest in relation to crop field (approximate distance from crop field)	Inside (0 m)	Inside or outside (0–1500 m)	Mainly orchard borders (~50 m)	Mainly inside (0 m)	Inside or outside (0–50 m)
Average bee foraging range (maximum distance from nest)	~50 m (~100 m)	~1200 m (10 km)	50–100 m (200 m)	10 – 50 m	*B. pascuorum* 500–2300 m; *B terrestris* 270–2800 m; *B. lapidarius* ~260 m
Time spent foraging or collecting nesting materials	10–15 min/d (individual bee)	~10–15 trips/d; 4–11 hrs/d (individual nectar forager); ~1.5 hrs/d (individual pollen forager)	2?	-	10–15 min/d (individual bee)
Period of the day when foraging or collecting nesting materials	Entire day	Mainly morning	Mainly morning	Mainly morning	Mainly morning
Time spent on the crop (for an individual bee)	~45 d	10–20 d	~20 d	~20 d	~20 d
Time spent on the crop (for the colony)	~45 d	~ 20 d	n.a.	n.a.	~20 d
Quantity of pollen collected	Little	200–300 mg/d; 10-30 mg/load	-	-	15–31 mg/d; 430–680 mg/ individual (total)
Quantity of nectar collected	None	250 µL/d; 25–40 mg/load	-	-	70 µL/load; 7–8 mL/individual (total)
Quantity of pollen consumed	-	~6.5 mg/d (nurse bee)	-	-	-
Quantity of nectar consumed	None	80–320 mg/d (forager)	-	-	Most of what is collected?
Body weight	160–270 (worker)	80–140 mg (worker)	85–110 mg	-	100–270 mg (worker)
% pollen self-consumed by adult	0%	Limited (early adult stage)	Little	Little	Little
% pollen fed to brood	100%	Most; stored and transformed	Up to 100%	Up to 100%	Up to 100%
% nectar self-consumed by adult	None	Some; most stored and transformed, and consumed as honey	Up to 100%	Up to 100%	Up to 100%
% nectar fed to brood	None	Most; stored and transformed and consumed as honey	Little	Little	Little
Collective pollen and/or honey storage in the nest	Yes	Yes	No	No	Yes
Overall likelihood of exposure compared to the European honey bee	**Greater**	**n.a.**	**Greater**	**Greater**	**Unclear**

- = data not available; ? = possibly; n.a. = not applicable; d = day; hr = hour; min = minute; mg = milligram; mL = millilitre; µL = microlitre
Sources: Questionnaire of this study, and: *Apis* [74, 77, 78, 107]; *Bombus* [79, 80, 81, 82, 83, 84, 90]; *Osmia* [50, 51, 52, 53, 85]

For the **Netherlands**, information was available for the honey bee and (commercially reared) *Bombus terrestris*. Only limited information was obtained on *Osmia rufa* and in particular on *Andrena*.

Bumblebees foraging on greenhouse tomato in the Netherlands are likely to be more exposed to pesticides than European honey bees foraging on open field crops in flower, because they are constrained to the greenhouse where all pesticide treatments take place. Therefore, both colony location and foraging are entirely in the treated crop area. Bumblebee body weight is higher than that of honey bees, which may reduce relative cuticular exposure per unit body weight. However, adult bumblebees in tomato do not consume pollen and tomato does not produce nectar, which means that exposure is mainly through contact. Bumblebee larvae, on the other hand, may be exposed to pollen contaminated by pesticides, but mainly by systemic pesticides. As tomato flowers shed pollen through small pores at the apices of pollen cones and anthers, spray contamination of pollen is likely to be limited.

In apple, both mason bees (*Osmia rufa*) and sand bees (*Andrena*) are likely to be more exposed to pesticides than European honey bees, considering bee biology factors. They nest inside the field or in field borders, and have a more limited foraging range. Furthermore, collected pollen is fed untransformed to brood. Other biology-related factors were either similar to the honey bee, or data were lacking. Biological exposure factors of bumblebee in apple orchards were similar to the two species of wild bees, but their body weight and foraging range are greater, which potentially reduces net exposure.

Overall, we conclude that there are still major data gaps regarding elements of bee biology that influence exposure risk of bees to pesticides. For most bee groups, information was available on daily and seasonal flight activity and on foraging patterns. On the other hand, information was lacking on foraging duration, quantities of pollen/nectar collected and amounts consumed by the foraging adults. In a companion publication to the present one, the existing natural history for major crop pollinating bee groups is compiled and assessed [109].

3.2.3 Exposure – pesticide use and application practices

The number of pesticide products and active ingredients (a.i.'s) registered and/or used on the focal crops in the three countries are summarized in Table 8.

In late 2011, 392 pesticide products were registered on tomato in **Brazil**, containing a total of 130 a.i.'s. In melon, 152 products were registered, containing 64 active ingredients.

Table 8

NUMBER OF PESTICIDES REGISTERED AND/OR USED IN THE FOCAL CROPS

	BRAZIL		KENYA				NETHERLANDS	
	MELON	TOMATO	CUCURBITS	COFFEE	FRENCH BEANS	TOMATO	APPLE	TOMATO
Number of active ingredients registered for use on the crop	64	130	11	9	17	23	72	61
Number of active ingredients used per crop	-	-	29	12	20	29	57	66
Number of active ingredients used in period when bees are active in the crop	-	-	25	0?	20	22	54	60
Number of insecticide/ acaricide active ingredients used in period when bees are active in the crop	-	-	13	0?	11	15	13	21
Systemic pesticides are applied as soil or seed treatment to a *previous* rotational crop	yes	yes	-	n.a.	-	-	n.a.	n.a.
Number of systemic pesticides used or registered per crop	35	49	14	5	10	12	28	24
Number of insect growth regulators used or registered per crop	4	15	0	0	0	0	3	6

- = data not available; ? = possibly; n.a. = not applicable

Annex 2 provides details on active ingredients used on both crops in Brazil. Pesticide application rates can also be obtained from the AgroFit database [30], but were not further analyzed in this assessment. Systemic pesticides were applied by soil or seed treatments to previous crops, which might pose a risk for exposure of bees to contaminated pollen or nectar in the subsequent melon or tomato crops.

Pesticide use on the focal crops in Kenya was assessed through farmer surveys. Annex 3 provides details on active ingredients used on all four crops in the country.

In coffee, 17 pesticide products were used in the survey area, containing 12 a.i.'s; all but three of these products were registered for use on coffee. Of the 17 products, at least 12 were used only after flowering, i.e. when bees were either non or less active in the coffee crop.

In cucurbits (mainly watermelon), 42 products were used in the survey areas, containing 29 different a.i.'s. Of these, 17 products (11 a.i.'s) were registered for use on cucurbits; the others were registered in Kenya but for use on other crops. This is due to the fact that watermelon is considered a minor crop and agrochemical companies have shown little interest in submitting registration applications for this crop. Only 5 products were used at planting or emergence of the watermelons, when bees would not be active (however 3 of these were systemic). Most other

pesticides were used throughout the growing season, including during flowering. In total, 33 pesticide products were used on French beans in the survey areas, containing 20 a.i.'s. Three products (3 a.i.'s) were not registered on French beans, but were authorized for use on other crops in Kenya. All pesticides were used throughout the crop cycle, or no specifications were given as to the period of use.

In tomato, 53 pesticide products were used in the survey areas, containing 29 a.i.'s. Of these, 7 products (6 a.i.'s) were not registered for use on tomato, but were authorized for use on other crops in Kenya. Most pesticides were used throughout the crop cycle, or no specifications were given as to the period of use; 5 a.i.'s were used at emergence or just after transplanting and would be less likely to affect bees (although 2 had systemic properties). Application rates were available for most products, but were not further used in this assessment. The use of systemic pesticides in previous rotational crops is not relevant in perennial crops such as coffee. In the other crops in Kenya, it was not known whether any systemic pesticides had been applied to previous rotational crops.

The number and types of pesticides registered per crop in **the Netherlands** could not be obtained through the public pesticide registration database maintained by the Dutch Board for the Authorization of Plant Protection Products and Biocides (Ctgb). The number of a.i.'s listed is based on information provided by the Dutch Plant Protection Service.

Pesticide usage data were available from Statistics Netherlands (CBS), for the year 2008 on a monthly basis (see Annex 4 for details). In tomato, 66 different a.i.'s were used, of which 60 were applied during the period that bumblebees would be active in the greenhouse. In apple, 57 a.i.'s were used, of which 54 were applied in periods that either honey bees or wild bees could be active in the apple orchard. It seems that in tomato more pesticide a.i.'s were used than were registered on this crop, although the discrepancy may be due to the difference in data sources. No data were available about individual products and application rates.

In the Netherlands, greenhouse tomato production always starts with fresh substrate, and previous crops are not relevant. Similarly, the use of systemic pesticides in previous rotational crops is not relevant in perennial crops such as apple.

3.2.4 Impact and recovery – pesticide properties

Pesticide toxicity data were available to a varying degree, depending on the bee species.

Acute toxicity data for the **western honey bee** (*A. mellifera*) are reported for most pesticides, as these tend to be required for pesticide registration. However, in many cases, only acute contact and oral test results obtained on adult worker bees are available.

On average, acute LD_{50} values for honey bees were available for 94 percent of the a.i.'s used in the various focal crops (Table 9 and Annexes 2, 3, 4). For only 70 percent of a.i.'s used on tomato in the Netherlands could an acute LD_{50} be found. This was partly due to the relatively large number of bio-pesticides and general disinfectants being used in that crop. Only few acute LD_{50} values for **bumblebees** were available.

Since application rates were not available for all crops, only a comparison of hazards could be made of the pesticides used in the different focal crops. The LD_{50} values (the lowest of the oral or contact LD_{50} was used) were classified according to the US-EPA hazard ranking for honey bees [25] (Table 9). The hazard classification for honey bee was then applied as a surrogate for all bees in this study.

The majority of pesticides used in both focal crops in the Netherlands were classified as practically non-toxic to bees. In Kenya the largest fraction of pesticides used was classified as highly toxic to bees, and this concerned all four crops. Both Brazilian crops were intermediate as to the hazard of the pesticides being used. Of the crops assessed in this study, the highest pesticide hazard to bees was found to be in cucurbits and tomatoes in Kenya; the lowest hazard in apple in the Netherlands.

The US-EPA toxicity classification primarily addresses the hazard of pesticides applied as a spray. Systemic pesticides applied as seed or soil treatment are not explicitly covered. However, a relatively large number of systemic pesticides are also being used on the focal crops (Table 8). The worst case toxicity–exposure ratio (TER), as defined by the EPPO for pesticides with systemic

Table 9

NUMBER OF ACUTE LD_{50} VALUES AVAILABLE FOR HONEY BEE AND BUMBLEBEE IN THE FOCAL CROPS, AND THEIR ASSOCIATED HAZARD

COUNTRY	CROP	NUMBER OF PESTICIDES REGISTERED/ USED	NUMBER OF PESTICIDES WITH AN ACUTE LD_{50} FOR HONEY BEE	NUMBER OF PESTICIDES WITH AN ACUTE LD_{50} FOR BUMBLEBEE	% PESTICIDES (no.) WHICH ARE		
					HIGHLY TOXIC[1] LD_{50} < 2 µg/bee	MODERATELY TOXIC 2 ≤ LD_{50} ≤ 11 µg/bee	PRACTICALLY NON-TOXIC LD_{50} > 11 µg/bee
Brazil	Melon	64	61	4	28% (17)	13% (8)	59% (36)
	Tomato	130	119	13	36% (43)	5% (6)	59% (70)
Kenya	Coffee	12	12	2	42% (5)	8% (1)	50% (6)
	Cucurbits	29	29	9	52% (15)	7% (2)	41% (12)
	French beans	20	20	5	40% (8)	5% (1)	55% (11)
	Tomato	29	28	7	50% (14)	7% (2)	43% (12)
Netherlands	Apple	57	52	5	10% (5)	11% (6)	79% (41)
	Tomato	66	52	5	21% (11)	8% (4)	71% (37)

1 Based on the hazard classification for honey bees according to the US-EPA [25]
For more details, see Annexes 2, 3 and 4

action, was also calculated. It is computed as: lowest oral LD_{50} value / 0.128, and represents maximum dietary exposure of a honey bee to a pesticide residue of 1 mg/kg in nectar [24].

It was found that whenever this systemic TER resulted in a high risk classification, the pesticide had already been categorized as highly toxic by the EPA oral/contact toxicity classification. One can therefore conclude that the EPA hazard classification is also "protective" for bees when systemic pesticides are concerned, at least for the compounds evaluated in this study.

Insect growth regulators (IGRs) tend to have a relatively low toxicity to adult bees, but may be very toxic to the larvae. A hazard classification based on acute LD_{50} obtained from adult bees is then not appropriate and toxicity data on bee brood are required [24]. Relatively few IGRs are being used on the focal crops (Table 7), and therefore no specific assessment of their risk was conducted.

Foliar residual toxicity data for honey bees were available for 42-71 percent of the pesticides with an LD_{50} < 11 µg/bee, the trigger used by the US-EPA to generate such data (Table 10 and Annex 2, 3, 4). These foliar residual toxicity data refer to maximum normal application rates in the USA, and these may not necessarily be the same in the three study countries. Furthermore, foliar residual dissipation is dependent on climatic circumstances, which may also differ between the US and the three countries covered in this study. The values compiled in the Annexes should therefore be considered as indicative.

In both Kenya and Brazil, a large fraction of pesticides had high residual toxicity; in the Netherlands this was less so. However, a relatively large fraction of pesticides with low residual toxicity still had a high or moderate acute contact toxicity to bees.

Table 10

FOLIAR RESIDUAL TOXICITY OF PESTICIDES IN THE FOCAL CROPS

COUNTRY	CROP	NUMBER OF PESTICIDES WITH LD_{50}<11 µg/BEE	NUMBER OF PESTICIDES WITH FOLIAR RESIDUAL TOXICITY DATA	NUMBER OF PESTICIDES WITH[1]		
				LOW RESIDUAL TOXICITY (< 4 hours)	MODERATE RESIDUAL TOXICITY (4 – 8 hours)	HIGH RESIDUAL TOXICITY (> 8 hours)
Brazil	Melon	26	11	4 {3}[2]	1	6
	Tomato	49	30	6 {4}	2	22
Kenya	Coffee	6	4	0 1	0	4
	Cucurbits	17	12	1 {1}	0	11
	French beans	9	6	1 {1}	0	5
	Tomato	16	10	1 {1}	0	9
Netherlands	Apple	11	5	3 {3}	0	2
	Tomato	15	10	7 {5}	0	3

1 Residual toxicity categories are based on [88].
2 Between brackets {..} is the number of pesticides with an acute LD_{50} < 11 µg/bee *and* having low residual toxicity. For more details, see Annexes 2, 3 and 4

3.2.5 Impact and recovery – life history and population dynamics

The life-history and population dynamics of the bee species will determine to a large extent how its populations will resist to or recover from such pesticide impact (Table 2). Tables 11, 12 and 13 summarize information compiled on factors related to life history and population dynamics of the bee groups present on the focal crops. It should be noted that these tables do not represent a complete literature review of the population dynamics of the listed species, and should therefore be considered indicative. As was done in Section 3.2.2, a comparison is made in the tables between the European honey bee and the other bees active in the crop. More complete information for some specific groups may be found in a companion pubication [109].

For **Brazil**, limited specific information was available for Africanized honey bee and the carpenter bee *Xylocopa grisescens*. The Africanized honey bee has a considerably higher population growth rate and swarming rate than the European subspecies. As a result, it can be expected

Table 11

FACTORS RELATED TO THE BEE'S LIFE-HISTORY AND POPULATION DYNAMICS WHICH MAY INFLUENCE THE IMPACT OF A PESTICIDE TO BEES IN THE FOCAL CROPS – BRAZIL

IMPACT – BEE LIFE HISTORY AND POPULATION DYNAMICS FACTORS	BRAZIL					
	MELON TOMATO	TOMATO				
	Apis mellifera (Africanized)	*Bombus*	*Xylocopa grisescens*	*Augochlora sp*	*Exomalopsis auropilosa*	*Melipona*
(Worker) metabolic rate	Hybrids < non-hybrid African or European subspecies	-	-	-	-	-
Degree of sociality	Eusocial	Primitively eusocial	Parasocial	Solitary	Parasocial	Eusocial
Fraction of adult population/colony active out of the nest/hive (social bees)	~35%	< 100%	Up to 100%	100%	100%	< 100%
Time to reproductive age of queen/ reproductive female (egg-adult)	~33 d	-	35 – 69 d	-	-	-
Number of offspring per queen/ reproductive female	8 – 12 offspring colonies/ parental colony/ yr	-	5 – 8/yr	-	-	-
Number of generations per year	3–4	-	1 – 4	-	-	-
Population growth rate [note: is product of previous 3 factors]	16-fold colony increase/yr	< honey bee	< honey bee	< honey bee	< honey bee	-
Number of swarms per colony per year	Up to 3, rarely more	n.a.	n.a.	n.a.	n.a.	-
Migration distance of swarms	> European subspecies (=500–600 m; max. 1600 m)	n.a.	n.a.	n.a.	n.a.	-
Overall likelihood of pesticide impact compared to the European honey bee	**Lesser**	**Greater**	**Greater**	**Greater**	**Greater**	**Unclear**

- = data not available; n.a. = not applicable; d = day; m = metre; yr = year
Sources: *Apis* [38, 107]; *Xylocopa* [60, 61, 62]; *Bombus* [101], General [73]

that the Africanized honey bee can recover quicker from pesticide-induced adverse effects on the population than the European honey bee.

It can be assumed that population growth rates of all the listed solitary and parasocial bees, will be lower than that of the honey bee. Also, the fraction of the total population which will be out of the nest foraging or collecting nesting materials will be greater for the solitary, parasocial and primitively eusocial bees, than for honey bees and stingless bees. As a result, it is likely that pesticide impact on individual bees will affect more of the populations of the carpenter bees, the solitary sweat bees, the long-horned bees and to a lesser extent the bumblebees, than of

Table 12

FACTORS RELATED TO THE BEE'S LIFE-HISTORY AND POPULATION DYNAMICS WHICH MAY INFLUENCE THE IMPACT OF A PESTICIDE TO BEES – KENYA

IMPACT – BEE LIFE HISTORY AND POPULATION DYNAMICS FACTORS	KENYA				
	COFFEE CUCURBITS FRENCH BEANS TOMATO	COFFEE CUCURBITS FRENCH BEANS TOMATO	COFFEE	FRENCH BEANS COFFEE	TOMATO CUCURBITS
	Apis mellifera scutellata	*Xylocopa*	*Patellapis*	*Megachilidae*	Halictidae
(Worker) metabolic rate	African subspecies > European subspecies	-	-	-	-
Degree of sociality	Eusocial	Parasocial	Solitary	Variable	Variable (solitary to primitively eusocial)
Fraction of adult population/colony active out of the nest/hive (social bees)	~35%	Up to 100%	100%	Variable	Variable
Time to reproductive age of queen/reproductive female (egg-adult)	~33 d	-	-	-	-
Number of offspring per queen/ reproductive female	> European subspecies	-	-	-	-
Number of generations per year	3–4	-	-	-	-
Population growth rate [note: is product of previous 3 factors]	16-fold colony increase/ yr	< honey bee	< honey bee	< honey bee	< honey bee
Number of swarms per colony per year	Up to 60 , though normally less	n.a.	n.a.	n.a.	n.a.
Migration distance of swarms	> European subspecies (=500–600 m; max. 1600 m)	n.a.	n.a.	n.a.	n.a.
Overall likelihood of pesticide impact compared to the honey bee	**n.a.**	**Greater?**	**Greater?**	**Greater?**	**Greater?**

- = data not available; ? = possibly; n.a. = not applicable; d =day; m = metre; yr = year
Sources: *Apis* [38, 100, 107]; Halictidae [65]; General [73].

the more social bees. In addition, the lower population growth rates would result in less rapid population recovery of these groups.

For **Kenya**, limited information was available for the African honey bee. Similar to the Africanized honey bee the African honey bee has considerably higher population growth rate and swarming rate than the European subspecies. As a result, it can be expected that the African honey bee can recover more quickly from pesticide-induced adverse effects on the population than the European honey bee. In addition, the higher metabolic rate of the African honey bee compared to European honey bee, may result in faster detoxification of certain pesticides in the former.

No specific data on life history and population dynamics for the other bee groups in Kenya was found. Based on the same reasoning as for Brazil about the degree of sociality and related fraction of adult bees that is active out of the nest, as well as the likely lower population growth rates, one could argue that population impact may be greater for the listed Kenyan non-*Apis* bees, and potential for recovery lower. However, this is not based on locally specific data.

For the **Netherlands**, information on life history and population dynamics was available for the honey bee and the red mason bee (*Osmia rufa*), and less so for bumblebees. No data were obtained for sand bees (*Andrena*). Greater population impact and less potential for recovery is very likely after adverse pesticide impact on *O. rufa* when compared to the honey bee. This is because all of the adult (reproductive) females of *O. rufa* are actively foraging outside the nest, contrary to the honey bee. Furthermore, population growth rates of *O. rufa* are lower than those of the honey bee.

Data for bumblebees were more limited. In tomato production in the Netherlands, commercially available colonies of bumblebees are placed and replaced in the greenhouse and population effects are not very relevant. However, adverse pesticide impact may temporarily affect bumblebee numbers and therefore pollination efficiency in the greenhouse. Queens of wild bumblebee species in northern Europe will hibernate as mated reproductive adults and start foraging and building a new colony in spring. Any pesticide impact on such reproducing bees will directly affect colony size and, if mortality occurs, preclude population recovery.

Table 13

FACTORS RELATED TO THE BEE'S LIFE-HISTORY AND POPULATION DYNAMICS WHICH MAY INFLUENCE THE IMPACT OF A PESTICIDE TO BEES – THE NETHERLANDS

IMPACT – BEE LIFE HISTORY AND POPULATION DYNAMICS FACTORS	THE NETHERLANDS				
	TOMATO	APPLE			
	Bombus terrestris	*Apis mellifera mellifera*	*Osmia rufa*	*Andrena*	*Bombus*
(Worker) metabolic rate	-	Lower than African subspecies	-	-	-
Degree of sociality	Primitively eusocial	Eusocial	Solitary	Parasocial?	Primitively eusocial
Fraction of adult population/colony active out of the nest/hive (social bees)	< 100%	~35%%	100%	100%	<100%
Time to reproductive age of queen/ reproductive female (egg-adult)	~33 d	~34 d	100 d	-	~33 d
Number of offspring per queen/ reproductive female	150–250	2.2 – 3.6 offspring colonies/parental colony/yr; ~38000 – 70000 workers/ queen/season; ~10 adult queens reared /colony/swarming cycle	Up to 20	-	~10 – 30
Number of generations per year	1	1–2	1	1	1
Population growth rate [note: is product of previous 3 factors]	< honey bee	0–3 -fold colony increase/yr	2.4 – 2.8 -fold population increase/yr	< honey bee	< honey bee
Number of swarms per colony per year	n.a.	2–4 (primary swarm & after swarms)	n.a.	n.a.	n.a.
Migration distance of swarms	n.a.	500–600 m (max. 1600 m)	n.a.	n.a.	n.a.
Overall likelihood of pesticide impact compared to the honey bee	**Greater**	**n.a.**	**Greater**	**Greater**	**Greater?**

- = data not available; ? = possibly; n.a. = not applicable; d =day; m = metre; yr = year
Sources: Questionnaire of this study, and: *Apis* [38, 102, 107]; *Osmia* [85, 89]; *Bombus* [101], General [73]

Pesticides being applied in a melon field in Juazeiro, Brazil.

CHAPTER 4
DISCUSSION

One of the objectives of the assessment of aspects determining risks of pesticides to wild bees was to identify data gaps for 'standard' risk assessment and to address the possibilities for an alternative risk profiling approach when required data are lacking. In addition, the study provides risk assessors with elements that can be used to develop pesticide risk mitigation measures.

4.1 DATA AVAILABILITY

The availability of data retrieved by the three participating countries is summarized in Table 14.

With respect to the **presence of bees** in the focal crops, generally it was known which groups of bees were active on the crop, although in a number of cases identification was only known along fairly broad taxonomic groups. The role of the wild bees as pollinators was relatively well known for melon in Brazil, coffee and French beans in Kenya, and tomato in the Netherlands. The lack of data for the other crops underlines the importance to obtain better insights on the exact role of wild bees as pollinators.

With respect to **exposure**, data were generally available for crop factors and for pesticide use and application factors, although in many cases these data were not complete. Data were limited or lacking especially for factors related to bee biology. As a consequence, it is often possible to infer the overall likelihood of exposure of wild bees in the focal crops. However, it is often not possible to further qualify or quantify the degree of exposure of individual bee taxa.

With respect to **impact and recovery**, toxicity data were available for most pesticides used in the focal crops. However, these were mainly limited to acute toxicity to honey bees. Few toxicity studies have been published for bumblebees, and even less so for other bee species. Foliar residual toxicity data were only obtained for roughly half of the more toxic pesticides for which these are normally generated, but to what extent these data can be used under different climatic conditions is uncertain. Availability of data on life history characteristics and population dynamics of, in particular, wild bees was poor or completely absent.

Table 14

AVAILABILITY OF DATA ON FACTORS THAT MAY INFLUENCE PESTICIDE RISK TO BEES FOR THE FOCAL CROPS

RISK FACTOR	BRAZIL		KENYA				NETHERLANDS	
	TOMATO	MELON	COFFEE	CUCURBITS	FRENCH BEANS	TOMATO	TOMATO	APPLE
Presence of bees								
Taxonomy	Limited	Good	Limited	Limited	Limited	Limited	Good	Limited
Pollination role	Limited	Good	Good	Limited	Good	Limited	Good	Limited
Exposure								
Crop factors	Good	Good	Good	Limited	Limited	Limited	Good	Good
Bee biology factors	Poor	Limited	Limited	Limited	Poor	Limited	Good	Limited
Pesticide use and application practices	Limited	Limited	Good	Good	Good	Good	Limited	Limited
Impact & recovery								
Pesticide properties	Limited							
Life-history and population dynamics	Limited	Poor	Poor	Poor	Poor	Poor	Limited	Limited

In conclusion, information was often available to give a first assessment of the likelihood of exposure of bees to pesticides in the focal crops, and the potential for adverse effects. However, it was generally not possible to make more detailed inferences about either the size and duration of adverse effects of the pesticide or the potential for recovery of the bees. In particular, bee biology, life-history and population dynamics would need to be studied in more detail. Furthermore, it is not known to what extent pesticide toxicity for honey bees is representative for wild bees. Finally, inclusion of application rates in the assessment would allow for a better quantification of risk, e.g. by calculating hazard quotients.

The need for further research on bee biology and ecology has also been expressed in the past, with the aim of gaining better understanding of pollination in Africa [92] and in Brazil [93]. Much of the research needed on pollination biology would also be of high value to pesticide risk profiling and assessment. Given the limited resources available for such research, it seems important that pesticide ecotoxicologists and pollination biologists seek active collaboration to optimize and mutually complement on-going and planned research efforts.

4.2 RISK PROFILES

The risk profiling approach used in this study was developed because a comprehensive risk assessment method for wild bees, or even for honey bees in non-temperate cropping systems, is not yet available. The results of this study indicate that important data gaps still exist with respect to, in particular, bee biology and quantification of exposure that may preclude the

establishment of a proper risk assessment procedure for wild bees in the near future. However, the elaboration of a risk profile, as outlined in this study, may provide a preliminary qualification of the risks of pesticide use to (wild) bees in specific crops.

There are important differences between a risk assessment and a risk profile. A risk assessment for bees, conducted for the registration of a pesticide, tends to focus on a specific pesticide product, includes a quantitative estimate of exposure and of effect, and refers to explicit acceptability criteria (e.g. the hazard quotient or toxicity-exposure ratio, in the EU/EPPO approach).

A risk profile, on the other hand, focuses on the cropping system. It includes (where possible) a quantitative measure of effects, but generally comprises only a qualitative (or semi-quantitative) estimate of exposure, and can therefore not quantify risks. As a result, explicit acceptability criteria are not used.

We consider risk profiling a particularly useful approach to:

- conduct a qualitative evaluation of pesticide risks to bees in specific cropping systems;
- compare potential risks of pesticide use to bees among cropping systems;
- facilitate discussion among researchers, regulators, farmers and beekeepers on pesticide risks to (wild) bees;
- identify data/information gaps;
- set priorities for further research (e.g. with respect to crops, bee groups, types of pesticides); and
- set priorities for risk mitigation.

In the absence of agreed quantitative risk assessment procedures for wild bees, or honey bees in (sub-) tropical cropping systems, establishing a risk profile provides a structured assessment of potential risks of pesticides to bees in a given crop situation while making explicit any data and knowledge gaps. This forms an excellent basis for discussion among researchers, regulators, farmers and beekeepers on how to value potential pesticide risks to bees and pollination in specific cropping systems.

The establishment of a risk profile further helps to set priorities for research, by identifying crops, species or groups of bees, or types of pesticides that merit additional study. For instance, additional research efforts would clearly be justified for pollinator-dependent cropping systems, where there is a great likelihood of exposure of bees to pesticides, and a large fraction of moderately toxic pesticides is being used, i.e. for which the resulting impact on bees may not be clear. Another priority example for research would be a pollinator-dependent crop, in which many highly toxic pesticides are being used, but where the likelihood and extent of exposure of

bees is not clear. The focus of research would be different according to the uncertainties that need to be clarified for the cropping system in question.

Even though risk profiling will often lead to less concrete conclusions about risk than formal risk assessment, the establishment of a risk profile could also lead to risk mitigation. In a number of cases, the outcome of a risk profile will be clear enough to warrant risk mitigation measures to be developed and/or to be taken. This would, for instance, be the case if there is a great likelihood of exposure of bees to various highly toxic pesticides in a highly pollinator-dependent crop. The risk of adversely affecting pollinators and crop production in such cases is so great that immediate implementation of risk mitigation measures is justified. The requirement for risk mitigation should, in such high risk cases, not be made conditional to the generation of further data or information.

Table 15 provides suggestions for priority setting for research and for developing (additional) risk mitigation on the basis of the outcome of a risk profiling exercise. Priorities are mainly based on the likelihood of exposure of bees on the one hand and the toxicity of the pesticides used in the crop on the other. Priorities are also based on the pollination dependency of the crop and the population dynamics of the bee. It is important to realize that this type of priority setting is relevant to risks of pesticides to bees in crops, in particular those that are to some extent dependent on pollination. It does not guide research or risk mitigation priorities unrelated to pollination, e.g. which focus on biodiversity protection. Other criteria are important for such aspects of bee conservation.

On the basis of the criteria in Table 15 and taking into account the data gaps which exist in many of the studied cases, the cropping situations assessed in this study can be categorized, in a preliminary manner, as shown in Table 16.

A high priority for identification and implementation of risk mitigation measures would be needed for cucurbits and tomato in **Kenya**, since these crops are highly dependent on bee pollination, there is a high likelihood of exposure of bees, and many highly toxic pesticides are being applied in the crops. On the other hand, there is a relatively low likelihood of exposure of bees in coffee, to a large extent because farmers already avoid spraying during flowering. Therefore, immediate development of additional risk mitigation does not seem warranted, and there is a lower priority for research about pesticide risks in this crop. French beans are not highly pollinator-dependent, and for that reason this crop may not be a priority for risk mitigation or research compared to some of the other crops assessed in the study. However, recent studies in Kenya are indicating significant yield increases from pollinator visits, making the dependence of this crop on pollinators as yet unclear [111].

Table 15

PRIORITY SETTING FOR RESEARCH OR FOR (ADDITIONAL) RISK MITIGATION, BASED ON THE OUTCOME OF A RISK PROFILE FOR A GIVEN CROPPING SYSTEM

PRIORITY FOR RESEARCH "R" , OR FOR (ADDITIONAL) RISK MITIGATION "M" (if in brackets [ ], the priority is secondary to the main priority)		**CROP DEPENDENCE ON POLLINATION**						
		HIGH			**LIMITED**			**NO**
		Likelihood of exposure of bees to pesticides			**Likelihood of exposure of bees to pesticides**			
		High	Low	Unclear	High	Low	Unclear	
Severity of impact Large fraction of the pesticides used in the crop are:	Highly toxic	**M [R]**		**R [M] §**	**M §**		**R §**	
	Moderately toxic	**R [M] §**		**R §**				
	Practically non- toxic	**R §**						

§ In particular if bee population dynamics or life history are likely to increase the severity of pesticide impact or reduce the speed of recovery

Table 16

PRIORITY SETTING FOR RESEARCH OR FOR RISK MITIGATION, BASED ON THE OUTCOME OF A RISK PROFILE FOR A GIVEN CROPPING SYSTEM

PRIORITY FOR RESEARCH "R", OR FOR RISK MITIGATION "M" (if in brackets [ ], the priority is secondary to the main priority)		**CROP DEPENDENCE ON POLLINATION**						
		HIGH			**LIMITED**			**NO**
		Likelihood of exposure of bees to pesticides			**Likelihood of exposure of bees to pesticides**			
		High	Low	Unclear	High	Low	Unclear	
Severity of impact Large fraction of the pesticides used in the crop are:	Highly toxic	**M, [R]** *Kenya:* cucurbits and tomato *Brazil:* melon and tomato	*Kenya:* Coffee		**M** *Kenya:* French beans			
	Moderately toxic							
	Practically non- toxic	**R§** *Netherlands:* apple and tomato						

§ Because bee population dynamics or life history are likely to increase the severity of pesticide impact or reduce the speed of recovery

In **Brazil**, there is a high number of highly toxic pesticides being used in melon and tomato, and the likelihood of exposure of bees is great. In addition, the information obtained about the life history and population dynamics of the wild bees points to an increased severity of pesticide impact and a lower capacity for population recovery. As a result, the priority would be to develop and implement risk mitigation measures for these crops. Research would then be needed to further quantify pesticide impact and refine mitigation options.

Even though the likelihood of exposure of bees to pesticides is high in apple and tomato in **the Netherlands**, most pesticides being used have a relatively low toxicity to bees. Apparently, risk mitigation in these crops has focussed on the choice of the pesticides being authorized and

used. There is a priority for research into pesticide effects however, in particular in apple, since population dynamics and life histories of the wild bees active in this crop may possibly result in increased severity of pesticide impact and reduced potential for population recovery.

It should be stressed that if the outcome of this type of priority setting is that there is less need for the development of risk mitigation measures, risk mitigation may still be necessary for the crop in question. Also, the fact that there is no immediate priority being identified for research in a specific crop, does not mean that additional research would not be useful. However, if resources are limited (which they almost always are), the identified priority is expected to provide the greatest benefits in reducing pesticide impact on bees in that specific crop.

This structured profiling exercise of pesticide risks to (wild) bees in different cropping systems on different continents has, according to current knowledge, not been carried out previously. The list of risk factors (Table 2) used in the assessment is definitely not exhaustive, and the possible effects these factors may have on pesticide risks to bees will clearly need further research. It is hoped that this present work can be used as a basis for conducting similar studies elsewhere (see Annex 1). Over time, this should result in a more precise set of risk factors, and progressively generate a more comprehensive database of risk profiles for different cropping systems and situations. In the long term, this risk profiling approach is expected to contribute to the development of formal risk assessment procedures for wild bees and for honey bees in agroecosystems.

Above: *Small-scale horticultural production in Kenya.*
Below: *Kenyan farmers learn about the diversity of insects visiting and pollinating their crops.*

*A carpenter bee (*Xylocopa*) visiting french bean flowers in Kenya.*

REFERENCES

[1] **Klein, A-M., Vaissière B., Cane J.H., Steffan-Dewenter, I., Cunningham, S.A., Kremen, C. & Tscharntke, T.** 2007. Importance of pollinators in changing landscapes for world crops. *Proceedings of the Royal Society London, B* 274**:** 303–313.

[2] **Aizen, M.A., Garibaldi, L.A., Cunningham, S.A. & Klein, A-M.** 2009**.** How much does agriculture depend on pollinators? Lessons from long-term trends in crop production. *Annals of Botany,* 103: 1579–1588.

[3] **Aizen, M.A., Garibaldi, L.A., Cunningham, S.A. & Klein, A-M.** 2008. Long-term global trends in crop yield and production reveal no current pollination shortage but increasing pollination dependency. *Current Biology,* 18**:** 1572–1575.

[4] **Garibaldi, L.A., Aizen, M.A., Klein, A-M., Cunningham, S.A. & Harder, L.D.** 2011. Global growth and stability of agricultural yield decreases with pollinator dependence. *PNAS,* 108: 5909–5914.

[5] **Gallai, N., Salles, J-M., Settele, J. & Vaissière, B.E.** 2009. Economic evaluation of the vulnerability of world agriculture confronted with pollinator decline. *Ecological Economics,* 68: 810–821.

[6] **Freitas, B.M. & Imperatriz-Fonseca, V.L.** 2005. A importância econômica da polinização. *Mensagem Doce,* 80: 44–46.

[7] **Kasina, J.M., Mburu, J., Kraemer, M. & Holm-Mueler, K.** 2009. Economic benefit of crop pollination by bees: a case study of Kakamega small-holder farming in western Kenya. *Journal of Economic Entomology,* 102: 467–473.

[8] **Munyuli, M.B.T.** 2011**.** Pollinator biodiversity in Uganda and in sub-Sahara Africa: landscape and habitat management strategies for its conservation. *International Journal of Biodiversity and Conservation,* 3: 551–609.

[9] **Blacquière, T., van Straalen, N. & Buiter, R. eds.** 2010. Bijen – Fascinerend, essentieel en bedreigd. Cahiers Bio-wetenschappen en Maatschappij, kwartaal 4, December 2010. The Hague, Stichting Bio-wetenschappen en Maatschappij.

[10] **Roubik, D.W. ed.** 1995. Pollination of cultivated plants in the tropics. FAO Agricultural Services Bulletin 118. Rome, FAO.

[11] **Heard, T.A.** 1999. The role of stingless bees in crop pollination. *Annual Review of Entomology,* 44: 183–206.

[12] **Breeze, T.D., Bailey, A.P., Balcombe, K.G. & Potts, S.G.** 2011. Pollination services in the UK: how important are honey bees? *Agriculture, Ecosystems and Environment,* 142: 137–143.

[13] **Potts, S.G., Biesmeijer, J.C., Kremen, C., Neumann, P., Schweiger, O. & Kunin, W.E.** 2010. Global pollinator declines: trends, impacts and drivers. *Trends in Ecology and Evolution,* 25: 345–353.

[14] **Neumann, P. & Carreck, N.L.** 2010. Honey bee colony losses (guest editorial). *Journal of Apicultural Research,* 49: 1–6.

[15] **Cameron, S.A., Lozier, J.D., Strange, J.P., Koch, J.B., Cordes, N., Solter, L.F. & Griswood, T.L.** 2011. Patterns of widespread decline in Northe American bumble bees. *PNAS,* 108: 662–667.

[16] **Biesmeijer, J.C., Roberts, S.P.M., Reemer, M., Ohlemüller, R., Edwards, M., Peeters, T., Schaffers, A.P., Potts, S.G., Kleukers, R., Thomas, C.D., Settele, J. & Kunun, W.E.** 2006. Parallel declines in pollinators and insect-pollinated plants in Britain and the Netherlands. *Science,* 313: 351–354.

[17] **Opera.** 2011. Bee health in Europe – facts & figures. Piacenza, Italy, OPERA Research Center, Università Cattolica del Sacro Cuore.

[18] **UNEP (United Nations Environment Programme).** 2010. UNEP emerging issues: global honey bee colony disorder and other threats to insect pollinators. Nairobi.

[19] **Le Féon, V., Schermann-Legionnet, A., Delettre, Y., Aviron, S., Billeter, R., Bugter, R., Hendrickx, F. & Burel, F.** 2010. Intensification of agriculture, landscape composition and wild bee communities: a large scale study in four European countries. *Agriculture, Ecosystems and Environment,* 137: 143–150.

[20] **Vandamme, R. & Palacio, M.A.** 2010. Preserved honey bee health in Latin America: a fragile equilibrium due to low-intensity agriculture and beekeeping? *Apidologie,* 41: 243–255.

[21] **Carvalho, S., Roat, T., Pereira, A.M., Silva-Zacarin E., Nocelli, R.C.F., Carvalho C. & Malaspina, O.** 2012. Losses of Brazilian bees: an overview of factors that may affect these pollinators. pp. 159-166 *In*: Hazards of pesticides to bees – 11th International Symposium of the ICP-BR Bee Protection Group. Wageningen, November 2-4, 2011. *P.A. Oomen & H. Thompson (eds)*. Julius-Künh-Archiv No. 437, Quedlinburg.

[22] **Kasina, M.J.** 2011. Bees require protection for sustainable horticultural production in Kenya. pp. 167-172 *In*: Hazards of pesticides to bees – 11th International Symposium of the ICP-BR Bee Protection Group. Wageningen, November 2-4, 2011. *P.A. Oomen & H. Thompson (eds)*. Julius-Künh-Archiv No. 437, Quedlinburg.

[23] **MEMR (Ministry of Environment and Mineral Resources).** 2011. Kenya national profile to assess the chemicals management. February 2011. Nairobi.

[24] **EPPO (European and Mediterranean Plant Protection Organization).** 2010. Environmental risk assessment scheme for plant protection products. Chapter 10: Honey bees. *Bulletin OEPP/EPPO Bulletin,* 40: 323–331.

[25] **US-EPA (United States Environmental Protection Agency).** Undated. Ecological risk assessment: technical overview. Office of Pesticide Programs. Available at http://www.epa.gov/oppefed1/ecorisk_ders/index.htm (accessed 29 September 2011).

[26] **EPHC (Environmental Protection and Heritage Council).** 2009. Environmental risk assessment guidance manual for agricultural and veterinary chemical. Canberra, Australia.

[27] **EFSA Panel on Plant Protection Products and their Residues (PPR)** 2012 Scientific Opinion on the science behind the development of a risk assessment of Plant Protection Products on bees (Apis mellifera, *Bombus* spp. and solitary bees). EFSA Journal 2012; 10(5) 2668. [275 pp.] doi:10.2903/j.efsa.2012.2668. Available online: www.efsa.europa.eu/efsajournal

[28] **Roubik, D.W.** 2002. Tropical agriculture: the value of honey bees to the coffee harvest. *Nature,* 417: 708.

[29] **Munyuli, T.** 2011. Factors governing flower visitation patterns and quality of pollination services delivered by social and solitary bee species to coffee in central Uganda. *African Journal of Ecology,* 49: 501–509.

[30] **AgroFit**, 2011. Sistema de Agrotóxicos Fitossanitários – AgroFit, Ministério da Agricultura, Pecuária e Abastecimento, Brazil. Available at http://agrofit.agricultura.gov.br/agrofit_cons/principal_agrofit_cons (accessed 19 October 2011 [melon] and 3 November 2011 [tomato]).

[31] **PCPB (Pest Control Products Board).** 2011. Registered pesticides in Kenya. Nairobi. Consulted in August 2011.

[32] **CBS.** 2008. Use of crop protection products per crop and active ingredient in 2008. Data set provided to Alterra. The Hague, Statistics Netherlands.

[33] **FAO/OSU** (undated) Database of pesticide acute toxic effects to honey bees. P. Jepson. Oregon State University & FAO, Rome.

[34] **Footprint PPDB.** 2011. Footprint Pesticide Properties Database (PPDB). University of Hertfordshire, UK. Available at http://sitem.herts.ac.uk/aeru/footprint/index2.htm (accessed 18 December 2011).

[35] **Footprint BPDB.** 2011. Footprint Bio-Pesticides Database (BPDB). University of Hertfordshire, UK. Available at http://sitem.herts.ac.uk/aeru/bpdb/index.htm (accessed 18 December 2011).

[36] **Mommaerts, V. & Smagghe, G.** 2011. Side-effects of pesticides on the pollinator *Bombus*: an overview. *In* M. Stoytcheva, ed. *Pesticides in the modern world – pests control and pesticides exposure and toxicity assessment*, Chapter 23, pp. 507–552. Rijeka, Croatia, InTech Open Access Publisher. Available at http://www.intechweb.org/books/show/title/pesticides-in-the-modern-world-pests-control-and-pesticides-exposure-and-toxicity-assessment

[37] **Tomlin, C.** 2010. The e-Pesticide Manual. 15th edition. Version 5.0.1. Alton, UK, British Crop Protection Council.

[38] **Schneider, S.S., DeGrandi-Hoffman, G. & Smith, D.R.** 2004**.** The African honey bee: factors contributing to a successful biological invasion. *Annual Review of Entomology,* 49: 351–376.

[39] **Siqueira, K.M.M., Ribeiro, M. de F., Kiill, L.H.P., Coelho M.S., Araújo D.C.S., Gama D. & Lima I.O.** 2011. Effect of agrochemicals on the pattern of visitation of honey bees (*Apis mellifera*) in melon (*Cucumis melo*). pp. 180-183 *In*: Hazards of pesticides to bees – 11th International Symposium of the ICP-BR Bee Protection Group. Wageningen, November 2-4, 2011. *P.A. Oomen & H. Thompson (eds)*. Julius-Künh-Archiv No. 437, Quedlinburg.

[40] **Njoroge, G.N., Gemmill, B., Bussmann, R., Newton, L.E. & Ngumi, V.W.** 2004. Pollination ecology of *Citrillus lanatus* at Yatta, Kenya. *International Journal of Tropical Insect Science,* 24: 73–77.

[41] **Njoroge, G., Njoroge, L. & Gemmill, B.** 2007. Watermelon in Kenya. *In* Crops, browse and pollinators in Africa: an initial stocktaking, pp. 20–21. African Pollinator Initiative. Rome, FAO.

[42] **Morimoto, Y., Gikungu, M. & Maundu, P.** 2004. Pollinators of the bottle gourd (*Lagenaria siceraria*) observed in Kenya. *International Journal of Tropical Insect Science,* 24: 79–86.

[43] **Mensah, B.A. & Kudom, A.A.** 2011. Foraging dynamics and pollination efficiency of *Apis mellifera* and *Xylocopa olivacea* on *Luffa aegyptiaca* Mill (Cucurbitaceae) in Southern Ghana. *Journal of Pollination Ecology,* 4: 34–38.

[44] **Tependino, V.J.** 1981. The pollination efficiency of the squash bee (*Peponapis pruinosa*) and the honey bee (*Apis mellifera*) on summer squash (*Cucurbita pepo*). *Journal of the Kansas Entomological Society,* 54: 359–377.

[45] **Artz, D.R. & Nault, B.A.** 2011. Performance of *Apis mellifera*, *Bombus impatiens*, and *Peponapis pruinosa* (Hymenoptera: Apidae) as pollinators of pumpkin. *Journal of Economic Entomology,* 104: 1153–1161.

[46] **Del Sarto, M.C.L., Peruquetti, R.C. & Campos, L.A.O.** 2005. Evaluation of the neotropical stringless bee *Melipona quadrifasculata* (Hymenoptera: Apidae) as pollinator of greenhouse tomatoes. *Journal of Economic Entomology,* 98: 260–266.

[47] **Karanja, R.H.N., Gikungu, M.W., Njoroge, G.N., Newton, L.E. & Kihoro, J.M.** 2011. Comparison of bee pollinators of coffee in organic and conventional farms. *Asian Journal of Agricultural Sciences,* 3: 469–474.

[48] **Ricketts, T.H.** 2004. Tropical forest fragments enhance pollinator activity in nearby coffee crops. *Conservation Biology,* 18: 1262–1271.

[49] **Jha, S. & Vandermeer, J.H.** 2009. Contrasting foraging patterns for Africanized honey bees, native bees and native wasps in a tropical agroforestry landscape. *Journal of Tropical Ecology,* 25: 13–22.

[50] **Reemer, M. & Klein, D.** 2010. Wilde bestuivers in apple-en perenboomgaarden in the Betuwe (*Wild pollinators in apple and pear ochards in the Betuwe*). Report no. EIS2010-04. Netherlands, Leiden, Stichting European Invertebrate Survey.

[51] **Vicens, N. & Bosch, J.** 2000. Pollinating efficacy of *Osmia cornuta* and *Apis mellifera* (Hyemnoptera: Megachilidae, Apidae) on 'Red Delicious' apple. *Environmental Entomology,* 29: 235–240.

[52] **Kuhn, E.D. & Ambrose, J.T.** 1984. Pollination of 'Delicious' apple by megachilid bees of the genus *Osmia* (Hymenoptera: Megachilidae) *Journal of the Kansas Entomological Society,* 57: 169–180.

[53] **Adamson, N.L.** 2011. An assessment of non-*Apis* bees as fruit and vegetable crop pollinators in Southwest Virginia. Dissertation submitted to the faculty of the Virginia Polytechnic Institute and State University. 3 February 2011. Blacksburg, Virginia, USA. Available at http://www.step-project.net/NPDOCS/Adamson_NL_D_2011.pdf

[54] **Kinuthia, W., Njoroge, L. & Gemmill-Herren, B.** 2007. Coffee in Kenya. *In* Crops, browse and pollinators in Africa: an initial stocktaking, pp. 46–50. Produced by the African Pollinator Initiative. Rome, FAO.

[55] **Krug, C., Alves-dos-Santos, I. & Cane, J.** 2010. Visiting bees of *Cucurbita* flowers (Cucurbitaceae) with emphasis on the presence of *Peponapis fervens* Smith (Eucerini – Apidae) – Santa Catharina, Southern Brazil. *Oecologia Australis*, 14: 128–139.

[56] **Taylor, O.M. & Cameron, S.A.** 2003. Nest construction and architecture of the Amazonian bumble bee (Hymenoptera: Apidae). *Apidologie,* 34: 321–331.

[57] **Cortopassi-Laurino, M., Knoll, F.R.N. & Imperatriz-Fonseca, V.L.** 2003. Nicho trófico e abundância de *Bombus morio* e *Bombus atratus* em diferentes biomas brasileiros. *In* G.A.R. Melo & I. Alves-dos-Santos, eds. *Apoidea Neotropica: Homenagem aos 90 anos de Jesus Santiago Moure*, pp. 285–295. Criciúma, Brazil, Editora UNESC.

[58] **Siqueira, K.M.M. de, Kiill, L.H.P., Martins, C.F., Lemos, I.B., Monteiro, S.P. & Feitoza, E. de A.** 2009. Ecologia da polinização do maracujá-amarelo, na região do Vale do Submédio São Francisco. *Revista Brasileira de Fruticultura,* 31: 1–12.

[59] **Kiill, L.H.P., Siqueira, K.M.M. de, Araújo, F.P. de, Monteiro, S.P., Feitoza, E. de A. & Lemos, I.B.** 2010. Biologia reproductiva de *Passiflora cincinnata* Mast. (Passifloraceae) na região de Petrolina (Pernambuco, Brazil). *Oecologia Australis,* 14: 115–127.

[60] **Camillo, E. & Garófalo, C.A.** 1989. Social organization in reactivated nests of three species of *Xylocopa* (Hymenoptera, Anthophoridae) in south-eastern Brazil. *Insectes Sociaux,* 36: 92–105.

[61] **Pereira, M. & Garófalo, C.A.** 2010. Biologia da nidificação de *Xylocopa frontalis* e *Xylocopa grisescens* (Hymenoptera, Apidae, Xylocopini) em ninhos-armadilha. *Oecologia Australis,* 14: 193–209.

[62] **Freitas, B.M. & Oliveira Filho, J.H. de.** 2001. Criação racional de mamangavas para polonização em áreas agrícolas. Fortaleza, Brazil, Banco do Nordeste.

[63] **Nocelli, R.C.F., Cintra-Socolowski, P., Roat, T.C., Ferreira, R.A.C., Pereira, A.M., Carvalho, S.M. & Malaspina, O.** In press. In: **Roubik, D.W.**, ed. Pollinator safety in agriculture. FAO, Rome.

[64] **Gikungu, M.W.** In press. *Assessment of large bees* (Xylocopa *and* Amegilla *species*) *exposure to pesticides*. In: **Roubik, D.W.**, ed. Pollinator safety in agriculture. FAO, Rome.

[65] **Martins, D.J.** In press. *Sweat bees (Halictidae) natural history and pesticide exposure routes*. In: **Roubik, D.W.**, ed. Pollinator safety in agriculture. FAO, Rome.

[66] **Boti, J.B., Campos, L.A. de O., Junior, P. de M., Vieira, M.F.** 2005. Influência da distância de fragmentos florestais na polinização da goiabeira. *Revista Ceres,* 52: 863–874.

[67] **Del Sarto, M.C.L., Peruquetti, R.C. & Campos, L.A.O.** 2005. Evaluation of the neotropical stingless bee *Melipona quadrifasciata* (Hymenoptera: Apidae) as pollinator of greenhouse tomato). Journal of *Economic Entomology,* 98: 260–266.

[68] **Kuhn-Neto, B., Contrera, F.A.L., Castro, M.S. & Nieh, J.C.** 2009. Long distance foraging and recruitment by a stingless bee *Melipona mandacaia*. *Apidologie,* 40: 472–480.

[69] **Fidalgo, A.O. & Kleinert, A.M.P.** 2007. Foraging behaviour of *Melipona rufiventris* Lepeletier (Apinae; Meliponini) in Ubatuba, SP, Brazil. *Brazilian Journal of Biology,* 67:133–140.

[70] **Fidalgo, A.O. & Kleinert, A.M.P.** 2010. Floral preferences and climate influence in nectar and pollen foraging by *Melipona rufiventris* Lepeletier (Hymenoptera: Meliponini) in Ubatuba, São Paulo State, Brazil. *Neotropical Entomology,* 39: 879–884.

[71] **Ferreira Junior, N.T., Blochtein, B. & Moraes, J.F. de.** 2010. Seasonal flight and resource collection patterns of colonies of the stingless bee *Melipona bicolor schencki* Gribodo (Apidae, Meliponini) in an Araucaria forest area in southern Brazil. *Revista Basileira de Entomologia,* 54: 630–636.

[72] P**ierrot, L.M. & Schlindwein, C.** 2003. Variation in daily flight activity and foraging patterns in colonies of uruçu – *Melipona scutellaris* Latreille (Apidae, Meliponini). *Revista Brasileira de Zoologia,* 20: 565–571.

[73] **Roubik, D.W.** 1989. Ecology and natural history of tropical bees. Cambridge, UK, Cambridge University Press.

[74] **Steffan-Dewenter, I. & Kuhn, A.** 2003. Honey bee foraging in differentially structured landscapes. *Proceedings of the Royal Society London B,* 270: 569–575.

[75] **Martins, D.J.** 2004. Foraging patterns of managed honey bees and wild bee species in an arid African environment: ecology, biodiversity and competition. *International Journal of Tropical Insect Science,* 24: 105–115.

[76] **Pasquet, R.S., Peltier, A., Hufford, M.B., Oudin, E., Saulnier, J., Paul, L., Knudsun, J.T., Herren, H.R. & Gepts, P.** 2008. Long-distance pollen flow assessment through evaluation of pollinator foraging range suggests transgene escape distances. *PNAS,* 105: 13456–13461.

[77] **Rortais, A., Arnold, G., Halm, M-P. & Touffet-Briens, F.** 2005. Modes of honey bees exposure to systemic insecticides: estimated amounts of contaminated pollen and nectar consumed by different categories of bees. *Apidologie,* 36: 71–83.

[78] **Eckert, C.D., Winston, M.L. & Ydenburg, R.C.** 1994. The relationship between population size, amount of brood, and individual foraging behaviour in the honey bee, *Apis mellifera* L. *Oecologia,* 97: 248–255.

[79] **Colla, S.** In press. *Bumble bees: natural history and pesticide exposure routes*. In: **Roubik, D.W.**, ed. Pollinator safety in agriculture. FAO, Rome.

[80] **Knight, M.E., Martin, P., Bishop, S., Osborne, J.L., Hale, R.J., Sanderson, R.A. & Goulson, D.** 2005. An interspecific comparison of foraging range and nest density of four bumblebee (*Bombus*) species. *Molecular Ecology,* 14: 1811–1820.

[81] **Walther-Herwig, K. & Frankl, R.** 2000. Foraging habitats and foraging distances of bumblebees, *Bombus* spp. (Hym., Apidae), in an agricultural landscape. *Journal of Applied Entomology,* 124: 299–306.

[82] **Darvill, B., Knight, M.E. & Goulson, D.** 2004. Use of genetic markers to quantify bumblebee foraging range and nest density. *Oikos,* 107: 471–478.

[83] **Wolf, S. & Moritz, R.F.A.** 2008. Foraging distance in *Bombus terrestris* L. (Hymenoptera: Apidae). *Apidologie,* 39: 419–427.

[84] **Chapman, R.E., Wang, J. & Bourke, A.F.G.** 2003. Genetic analysis of spatial foraging patterns and resource sharing in bumble bee pollinators. *Molecular Ecology,* 12: 2801–2808.

[85] **Gruber, B., Eckel, K., Everaars, J. & Dormann, C.** 2011. On managing the red mason bee (*Osmia bicornis*) in apple orchards. *Apidologie,* 42: 564–576.

[86] **US-EPA (United States Environmental Protection Agency).** 2011. *Interim guidance on honey bee data requirements*. Memorandum, 19 October 2011. Washington DC.

[87] **Sanford, M.T.** 1993. Protecting honey bees from pesticides. Gainesville , Florida, USA, Florida Cooperative Extension Service, University of Florida.

[88] **Riedl, H., Johansen, E., Brewer, L. & Barbour, J.** 2006. How to reduce bee poisoning from pesticides. Pacific Northwest Extension Publication No. 591. Corvallis, Oregon, USA, Oregon State University.

[89] **van der Steen, J.** 1993. Biologie en toepassing van de solitaire bij *Osmia rufa* L. *Maandblad voor Imkers*: januari 1993.

[90] **Schmid-Hempel, R. & Schmid-Hempel, P.** 1998. Colony performance and immunocompetence of a social insect, *Bombus terrestris*, in poor and variable environments. *Functional Ecology*, 12: 22–30.

[91] **Silva, P.N., Hrncir, M. & Imperatriz-Fonseca, V.L,** 2010. A polinização por vibração. *Oecologia Australis,* 14: 140–151.

[92] **Rodger, J.G., Balkwill, K. & Gemmill, B.** 2004. African pollination studies: where are the gaps? *International Journal of Tropical Insect Science,* 24: 5–28.

[93] **Imperatriz-Fonseca, V.L., Saraiva, A.M. & De Jong, D. eds.** 2006. Bees as pollinators in Brazil: assessing the status and suggesting best practices. Proceedings of the Workshop on São Paulo Declaration on Pollinators plus 5 Forum, São Paulo, Brazil, 27–31 October 2003. Conservation International – Brazil, Ribeirão Preto.

[94] **Raina, S.K. & Kimbu, D.M.** 2007. Variations in races of the honey bee *Apis mellifera* (Hymenoptera: Apidae) in Kenya. *International Journal of Tropical Insect Science*, 25: 281–291.

[95] **Biovision.** 2011. *Beekeeping*. Available at http://www.infonet-biovision.org/default/ct/276/livestockSpecies (accessed 20 December 2011).

[96] **Ndiritu, D.W., Mutugi, N. & Ndung'u, S.** 1986. Variation in malate dehydrogenase allozymes among honey bee populations in Kenya. *Journal of Apicultural Research,* 25: 234-237.

[97] **Ibarra-Perez, F.J., Barnhart, D., Ehdaie, B., Knio, K.M., & Waines, J.G.** 1999. Effects of insect tripping on seed yield of common beans. *Crop Science,* 39: 428–433.

[98] **Aebi, A., Vaissière, B.E., vanEngelsdorp, D., Delaplane, K.S., Roubik, D.W. & Neuman, P.** 2012. Back to the future: *Apis* versus non-*Apis* pollination. *Trends in Ecology and Evolution,* 27: 142–143.

[99] **Bosa, E., Okoli, F.L.S. & Onofeghara, F.A.** 1984. Distribution and morphology of extrafloral nectaries in some Cucurbitaceae. *Botanical Journal of the Linnean Society,* 89: 153–164.

[100] **Harrison, J.F. & Hall, H.G.** 1993. African-European honeybee hybrids have low non-intermediate metabolic capacities. *Nature,* 363: 258–260.

[101] **Van der Steen, J.J.M.** 2008. Infection and transmission of *Nosema bombi* in *Bombus terrestris* colonies and its effect on hibernation, mating and colony founding. *Apidologie,* 39: 273–282.

[102] **Lee, P.C. & Winston, M.L.** 1987. Effects of reproductive timing and colony size on the survival, offspring colony size and drone production in the honey bee (*Apis mellifera*). *Ecological Entomology,* 12: 187–195.

[103] **Jauker, F., Bondarenko, B., Becker, H.C. & Steffan-Dewenter, I.** 2012. Pollination efficiency of wild bees and hoverflies provided to oilseed rape. *Agricultural and Forest Entomology,* 14: 81–87.

[104] **Rader, R., Howlett, B.G., Cunningham, S.A., Wescott, D.A. & Edwards, W.** 2012. Spatial and temporal variation in pollinator effectiveness: do unmanaged insects provide consistent pollination services to mass flowering crops? *Journal of Applied Ecology,* 49: 126–134.

[105] **Kovács-Hostyánszki, A., Batáry, P. & Báldi, A.** 2011. Local and landscape effects on bee communities of Hungarian winter cereal fields. *Agricultural and Forest Entomology,* 13: 59–66.

[106] **Velthuis, H.H.W.** 1997. *The biology of stingless bees*. Utrecht, Netherlands, Department of Ethology, Utrecht University.

[107] **Winston, M.L.** 1991. *The biology of the honey bee*. Cambridge, USA, Harvard University Press.

[108] **Williams, G.R., Tarpy, D.R., vanEngelsdorp, D., Chauzat, M-P., Cox-Foster, D.L., Delaplane, K.S., Neumann, P., Pettis, J.S., Rogers, R.E.L. & Shutler, D.** 2010. Colony collapse disorder in context. *Bioessays,* 32: 845–846.

[109] **Roubik, D.W.**, ed. 2013. Pollinator safety in agriculture. FAO, Rome.

[110] **Aizen, M.A. & L.D. Harder. 2009.** The global stock of domesticated honey bees is growing slower than agricultural demand for pollination. Current Biology, 19: 915-918.

[111] **Masiga R., Odhiambo C., Kinuthia W., Kasina M.** (in submission). Pollination deficit assessment in Kenya.

[112] **Fisher, D. & Moriarty, T.** 2011. Pesticide risk assessment for pollinators: Summary of a SETAC Pellston Workshop. 15–21 January 2011. Pensacola, Florida, USA, Society for Environmental Toxicology and Chemistry (SETAC).

Above: *Passionfruit grower in Brazil inspecting his fruit for pests or disease.*
Below: *Smallholder farmer in Brazil removing weeds from his cowpea fields.*

ANNEX 1
ASPECTS DETERMINING RISK OF PESTICIDES TO BEES: SURVEY FORM TO ESTABLISH A RISK PROFILE

To be able to elaborate a risk profile for bees of pesticide use in a specific crop, information is needed on three aspects: (i) the toxicity of the pesticide; (ii) the probability of exposure of the bee to that pesticide; and (iii) the population dynamics of the bee species in question.

Pesticide **toxicity** data have mainly been generated for the western honey bee (*Apis mellifera*), but much less so for other *Apis* species or non-*Apis* bees (both wild and managed). Increasingly, however, toxicity tests are being done with *non-Apis melllifera* species, although not all of these have found their way into the international published literature.

The probability and degree of **exposure** to pesticides depend on cropping and pesticide application practices, pesticide properties, attractiveness of the crop to bees, and bee biology (in particular phenology and behaviour). Data on these aspects of exposure, for a given crop in a given country or region, may be available from agricultural extension services, pesticide registration authorities, bee experts, agronomists and environmental scientists.

Finally, the **population dynamics** of the bee species will determine how an observed effect of the pesticide (either lethal or sublethal) will affect long-term survival of the population.

It is not likely that the information listed in the questionnaire is all available from one institution or person in the country. It is certainly necessary to consult with agronomists, extension services and farmer associations working in the focal crops to obtain cropping and pesticide use data; with the pesticide registration authority and research organizations to obtain pesticide property and toxicity data; and with bee and pollination experts to obtain bee biology information. All the information has been compiled into one questionnaire, however, to underline the interdisciplinary nature of pesticide risk assessment.

Some information will be available from the published literature; other data may be obtained from local unpublished report or studies, or be provided through expert opinion. All such information can be very relevant for risk assessment and should be compiled. However, to be able to allow proper interpretation of the data, it is important to provide the source(s) of each input in the table, irrespective of whether they are published reports/articles or personal communications. If data/information is unavailable or unknown, please also explicitly mention this as it will help identify gaps in our knowledge. Finally, it is helpful to list all the institutions and persons that were consulted for the assessment.

A. Case identity

The assessment can be done on a country-wide basis if the cropping systems and bee complexes are similar throughout the country, or on a regional basis if important differences exist within the country.

Country:	
Region (optional):	
Crop:	Number of growing seasons per year:
Main bee species/groups visiting the crop:	Is species an important pollinator of the crop?
1.	yes/ no/ not known
2.	yes/ no/ not known
3.	yes/ no/ not known

B. Exposure – crop factors

Assessment of whether there is a possibility of exposure of bees to the pesticide in this crop.

This information should allow a first evaluation as to whether bees may be exposed to pesticides in the crop. This is the case when they are likely to be active foraging for pollen or (extrafloral) nectar in the crop, or when they are collecting nesting materials, when (or just after) pesticides are applied to that crop. Bees may also be exposed if a systemic pesticide has been applied to a previous rotational crop. If exposure is unlikely, pesticide risk to wild bees is considered to be low, and obtaining information on the aspects below is not necessary.

FACTOR		REMARKS	SOURCE OF INFORMATION *(refer to section G)*
Surface area under the crop		Within the overall area for which the assessment is done	
○ Overall size		ha	
○ Patchiness		Percent of total area with this crop	
Period(s) in the growing season when pesticides are applied to the crop:		Note the month(s)/ date(s)/ or timing relative to emergence, flowering or harvest	
Period(s) in the year when the crop is grown:		Note the month(s)	
Period(s) in the year when the crop flowers:		Note the month(s)	
Period(s) in the year when the bee species/groups are active foraging or collecting nesting materials outside the nest/hive:	1.	Note the species/group and the month(s)	
	2.		
	3.		
Are any weeds flowering in the crop that may be attractive to bees? If yes: Period(s) during the crop season when weeds are flowering:		yes/no if yes: note the month(s)	
Does the crop have extrafloral nectaries that may be attractive to bees?		yes/no	
Is the crop regularly infested with honeydew producing insects (e.g. aphids, scale insects) that may be attractive to bees?		yes/no	
Do the bees likely visit the treated crop to collect water (e.g. dew on crop? open water in/near crop?)		yes/no	
Are any systemic pesticides applied as soil treatment or seed treatment to a previous rotational crop?		yes/no	
Do male bees “roost” in the crop, at night?		yes/no	
Do male bees establish mating sites in the crop?		yes/no	

C. Exposure – bee biology factors

This section contains relevant information on bee biology that may partly determine pesticide risk. Please provide information for each bee species/group identified under section A. Please also provide references to published literature or unpublished research reports when possible. Indicate when information is expert opinion, and note the name(s) of the expert(s). If the information is unavailable, please explicitly note this.

FACTOR	BEE SPECIES/GROUP			REMARKS	SOURCE OF INFORMATION *(refer to section G)*
	1:	2:	3:		
Period of the day when foraging or collecting nesting materials (outside the nest):					
Time spent foraging, or collecting nesting material, per day ("time-out-of-nest/hive"):				hours	
Number of days spent foraging on the crop (for an individual bee):				days	
Number of days spent foraging on the crop (for the colony):				days	
Number of different nectar and pollen plant species used during crop flowering:					
Quantity of pollen collected per day:				mg per bee per day	
Quantity of nectar collected per day:				mg per bee per day	
Quantity of nectar consumed per day:				mg per bee per day	
Body weight:				mg	
Percent of pollen self-consumed:					
Percent of pollen fed to brood:					
Percent of nectar self-consumed:					
Percent of nectar fed to brood:					
Location of nest in relation to crop field –					
Inside/outside crop field:					
Approximate distance from crop field:				m	
Bee foraging range –					
Average distance from nest:				m	
Maximum distance from nest:				m	
Collective pollen and/or honey storage in the nest (social bees):				yes/no	
Other aspects of bee biology or behaviour that may impact exposure:					

D. Exposure and impact – pesticide use/application practices

This section contains relevant information on the types of pesticides used in the focal crop, and the application practices. If actual pesticide use data are unavailable, pesticide registration data can also be used. If the information is unavailable, please explicitly note this as well.

PRODUCT NAME	**FORMULATION TYPE** (CODE)	**COMMON NAME (A.I.)**	**REGISTERED?** (yes/no)	**USED?** (yes/no)	**SYSTEMIC?** (yes/no)	**IGR?** (yes/no)	**MODE OF APPLICATION** (spray, seed treatment, soil treatment, dusting …)	**APPLICATION RATE** (g/a.i. per ha)	**APPLICATION FREQUENCY** (number of applications per growing season)	**APPLICATION TIMING** (date/ or month/ or timing relative to cropemergence, flowering or harvest)	**SOURCE OF INFORMATION** (registration data, farmer, extension, other *(specify)* *(refer to section G)*

E. Impact and recovery – pesticide properties

This section contains relevant information on the properties of all the pesticide active ingredients used on the crop. These aspects are independent of the actual pesticide use practices described above. Provide references to published literature or unpublished research reports when possible. If the information is unavailable, explicitly note this as well. Use more pages, if needed.

PESTICIDE PROPERTY	BEE SPECIES/GROUP				REMARKS	SOURCE OF INFORMATION (*refer to section G*)
	1:	2:	3:	4: *Apis mellifera*		
Pesticide i.						
Contact LD_{50} (adult)					□g/bee	
Oral LD_{50} (adult)					□g/bee	
Brood toxicity					only for IGRs	
Foliar residual toxicity					in days; note application rate	
Pesticide ii.						
Contact LD_{50} (adult)					□g/bee	
Oral LD_{50} (adult)					□g/bee	
Brood toxicity					only for IGRs	
Foliar residual toxicity					in days; note application rate	
Pesticide iii.						
Contact LD_{50} (adult)					□g/bee	
Oral LD_{50} (adult)					□g/bee	
Brood toxicity					only for IGRs	
Foliar residual toxicity					in days; note application rate	
Pesticide iv.						
Contact LD_{50} (adult)					□g/bee	
Oral LD_{50} (adult)					□g/bee	
Brood toxicity					only for IGRs	
Foliar residual toxicity					in days; note application rate	

Etc.

F. Impact and recovery – life history and population dynamics factors

This section contains relevant information on bee life histories and population dynamics that may partly determine pesticide risk. Please provide information for each bee species/group identified under section A. Please also provide references to published literature or unpublished research reports when possible. Indicate when information is expert opinion, and note the name(s) of the expert(s). If the information is unavailable, please explicitly note this.

FACTOR	BEE SPECIES/GROUP			REMARKS	SOURCE OF INFORMATION *(refer to section G)*
	1:	2:	3:		
Individual metabolic rate					
Degree of sociality					
Fraction of population/colony active out of the nest/hive (social bees)					
Time to reproductive age of queen/reproductive female (egg-adult)				days	
Number of offspring per queen/ reproductive female					
Number of generations per year					
Population growth rate [note: as product of previous 3 factors]				Colony multiplication factor per unit time; or number per reproductive female per unit time	
Number of swarms per colony or reproductive events per year					
Migration and dispersal distance				km	

G. Sources

In this section, all the institutions and persons consulted are listed, even if they were not able to provide information or data.

REFERENCE IN PREVIOUS SECTIONS (NO.)	**INSTITUTION OR PERSON CONSULTED**	**ASPECT**	**CONTACT DETAILS** (e-mail address and/or telephone number)

Etc.

References to reports, articles, studies, etc. can be listed here.

REFERENCE IN PREVIOUS SECTIONS (NO.)	**TITLE OF REPORT, ARTICLE, STUDY**	**AUTHOR(S)**	**PUBLICATION DETAILS**

Etc.

ANNEX 2[1]
PESTICIDES REGISTERED ON THE FOCAL CROPS – BRAZIL

ACTIVE INGREDIENT	TYPE	SYSTEMIC	IGR	LD_{50} HONEY BEE (µg/bee)		LD_{50} BOMBUS SPP. (µg/bee)	FOLIAR RESIDUAL TOXICITY (hours or days)	REGISTERED ON	
				LOWEST	ORAL	LOWEST		MELON	TOMATO
Abamectin	I, A	Lim.	No	*0.002*			8-72hr	X	X
Acephate	I, A	No	No	0.36		3.69 (*B. terrestris*)	>72hr	X	X
Acetamiprid	I	Yes	No	8.1	14.5	2.1 (*B. patagiatus*)		X	X
Alanycarb	I	No	No	0.80					X
Alpha-cypermethrin	I	No	No	0.036		0.15 *(B. terrestris)*			X
Anilazine	F	No	-	*100*					X
Azocyclotin	A	No	No	>5					X
Azoxystrobin	F	Yes	-	>25				X	X
Bacillus thuringiensis	I	No	No	>0.1				X	X
Benalaxyl	F	Yes	-	*>100*					X
Benfuracarb	I	Yes	No	0.29					X
Benzalkonium chloride	F, B	?	-	n.a.					X
Beta-cyfluthrin	I	No	No	*0.001*				X	X
Beta-cypermethrin	I	No	No	0.13					X
Bifenthrin	I, A	No	No	0.013			>24hr	X	X
Bitertanol	F	No	-	104				X	
Boscalid	F	Lim.	-	*100*				X	X
Bromuconazole	F	Yes	-	100					X
Buprofezin	I, A	No	Yes	>200				X	X
Captan	F	No	-	26.4				X	X
Carbaryl	I, PGR	Lim.	No	1.70		3.84 (*n.i.*)	2-14d		X
Carbofuran	I, N	Yes	No	0.15			>5d		X
Carbosulfan	I	Yes	No	0.68			3.5d		X

follows on the next page →

1 ***Registered pesticides:*** AgroFit database, Ministério da Agricultura, Pecuária e Abastecimento (2011) [30]; ***Type, systemicity, IGR:*** Tomlin (2011) [37], Footprint PPDB (2011) [34]; ***Acute LD_{50} honey bee*** (oral or contact): FAO/OSU (2011) [33]. If missing in previous, Footprint PPDB (2011) [34] and Footprint BPDB (2011) [35] – *in italics in table;* ***Acute LD_{50} bumblebee***: Mommaerts & Smagghe (2011) [36]; ***Foliar residual toxicity:*** Pacific Northwest Extension [88] & Florida Cooperative Extension Service [87]; determined for the honey bee at maximum normal US application rates.

ACTIVE INGREDIENT	TYPE	SYSTEMIC	IGR	LD_{50} HONEY BEE (µg/bee)		LD_{50} BOMBUS SPP. (µg/bee)	FOLIAR RESIDUAL TOXICITY (hours or days)	REGISTERED ON	
				LOWEST	ORAL	LOWEST		MELON	TOMATO
Cartap hydrochloride	I	Yes	No	10				X	X
Chlorfenapyr	I, A	Lim.	No	0.12			<4h	X	X
Chlorfluazuron	I	No	Yes	>100					X
Chromafenozide	I	No	Yes	>100					X
Chlorothalonil	F	No	-	181				X	X
Clethodim	H	Yes	--	>100					X
Clothianidin	I	Yes	No	0.044	9.92			X	X
Copper hydroxide	F	No	-	>100				X	X
Copper oxychloride	F	No	-	15				X	X
Copper oxyde	F	No	-	*>116*					X
Copper sulfate	F	No	-	>11				X	
Cyazofamid	F	No	-	>100					X
Cyfluthrin	I	No	No	0.019		0.13 (*n.i.*)	>24h		X
Cymoxanil	F	Yes	-	25	100				X
Cypermethrin	I	No	No	0.03			>3d		X
Cyproconazole	F	Yes	-	100	1000			X	
Cyprodinil	F	Yes	-	316					X
Cyromazine	I	Yes	Yes	20			<2h	X	X
Deltamethrin	I	No	No	0.017		0.6 (*B. terrestris*)	<4h	X	X
Diafenthiuron	I	No	No	1.5				X	X
Difenoconazole	F	Yes	-	101	187			X	X
Diflubenzuron	I	No	Yes	100					X
Dimethoate	I, A	Yes	No	0.098		4.8 (*B. terrestris*)	3d		X
Dimethomorph	F	Yes	-	100					X
Dodec-7-enyl acetate	Ph	No	-	n.a.					X
Esfenvalerate	I	No	No	0.045			24h		X
Ethion	I, A	No	No	4.18				X	X
Etofenprox	I	No	No	0.13					X
Etoxazole	A	No	Yes	200					X
Famoxadone	F	No	-	>63					X
Fenamidone	F	Yes	-	75	160			X	X
Fenamiphos	N	Yes	No	1.43				X	X
Fenarimol	F	Yes	-	100				X	
Fenpropathrin	I, A	No	No	0.05			24h		X
Fenpyroximate	A	No	Lim.	*15.8*					X
Fenthion	I	No	No	0.056				X	

follows on the next page →

ACTIVE INGREDIENT	TYPE	SYSTEMIC	IGR	LD_{50} HONEY BEE (µg/bee)		LD_{50} BOMBUS SPP. (µg/bee)	FOLIAR RESIDUAL TOXICITY (hours or days)	REGISTERED ON	
				LOWEST	ORAL	LOWEST		MELON	TOMATO
Flazasulfuron	H	Yes	-	>100					X
Fluazifop-P-butyl	H	Yes	-	112	200				X
Fluazinam	F	No	-	100					X
Fluquinconazole	F	Yes	-	>100				X	
Flutriafol	F	Yes	-	5				X	
Folpet	F	No	-	33.8				X	
Formetanate	I, A	No	No	10.6					X
Gamma-cyhalothrin	I	No	No	*0.005*					X
Hexadec-11-enyl acetate	Ph	No	-	n.a.					X
Hexadeca-E-11	Ph	No	-	n.a.					X
Imibenconazole	F	Yes	-	125				X	
Imidacloprid	I	Yes	No	0.004		0.02 (*B. terrestris*)	>24h	X	X
Indoxacarb	I	No	No	0.40				X	X
Iprodione	F	No	-	400				X	X
Iprovalicarb	F	Yes	-	>199				X	X
Kasugamycin	F, B	Yes	-	>25					X
Kresoxim-methyl	F	No	-	14				X	X
Lambda-cyhalothrin	I	No	No	0.093		0.11 (*n.i.*)	>24h		X
Lufenuron	I, A	No	Yes	197					X
Malathion	I	No	No	0.47			5.5d		X
Mancozeb	F	No	-	>20				X	X
Maneb	F	No	-	12					X
Metalaxyl-M	F	Yes	-	200				X	X
Metam sodium	F, N, H, I	No	No	36.2					X
Methamidophos	I, A	Yes	No	0.1			24hr		X
Metconazole	F	Yes	-	97				X	X
1-methylcyclopropene	PRG	No	-	n.a.				X	X
Methiocarb	I, A, M	No	No	0.37			>3d		X
Metiram	F	No	-	40				X	X
Methomyl	I, A	Yes	No	0.42		0.57 (*B. terrestris*)	1.5d		X
Methyl bromide	I, A, N	No	No	n.a.				X	
Methyl-eugenol	Ph	No	-	n.a.					X
Methoxyfenozide	I	No	Yes	>100					X
Metribuzin	H	Yes	-	35					X
Mevinphos	I, A	Yes	No	0.086			<1.5d	X	X

follows on the next page →

ACTIVE INGREDIENT	TYPE	SYSTEMIC	IGR	LD_{50} HONEY BEE (µg/bee)		LD_{50} BOMBUS SPP. (µg/bee)	FOLIAR RESIDUAL TOXICITY (hours or days)	REGISTERED ON	
				LOWEST	ORAL	LOWEST		MELON	TOMATO
Milbemectin	A	Lim.	No	0.025	0.46				X
Myclobutanil	F	Yes	-	>7				X	
Napropamide	H	Yes	-	121					X
Novaluron	I	No	Yes	>100					X
Oxytetracycline	B	Yes	-	>100					X
Permethrin	I	No	No	*0.029*		0.81 (*B. terrestris*)	0.5-2d		X
Phenthoate	I, A	No	No	0.3					X
Phorate	I, A, N	Yes	No	1.12		1-2 (*B. lucorum*)	24h		X
Pirimicarb	I	Yes	No	6.21		8.5 (*B. terrestris*)	<2h		X
Prochloraz	F	No	-	37.4					X
Procymidone	F	Yes	-	100				X	X
Profenofos	I, A	No	No	1.23					X
Propargite	A	No	No	15					X
Propamocarb hydrochloride	F	Yes	-	100	116				X
Propiconazole	F	Yes	-	14.1					X
Propineb	F	No	-	200					X
Prothiofos	I	No	No	n.a.					X
Pymetrozine	I	?	No	117			<2h	X	X
Pyraclostrobin	F	Lim.	-	73				X	X
Pyrazophos	F	Yes	-	0.65	0.84			X	
Pyridaphenthion	I	No	No	*0.08*					X
Pyrimethanil	F	Lim.	No	>100				X	X
Pyriproxyfen	I	No	Yes	>100				X	X
Quinomethionate	A, F	No	No	n.a.				X	
Quintozene	F	No	-	*100*					X
Quizalofop-P-ethyl	H	No	-	71					X
Spinosad	I	No	No	0.003			<2h		X
Spirodiclofen	I, A	No	Yes	*>196*					X
Spiromesifen	I, A	No	Yes	*>200*				X	X
Streptomycin	B	Yes	-	>100					X
Sulphur	F, A	No	-	1051				X	X
Tebuconazole	F	Yes	-	176				X	X
Tebufenozide	I	No	Yes	234			<8h		X
Teflubenzuron	I	No	Yes	1000					X
Tetraconazole	F	Yes	-	>130				X	X
Tetradec-3,8,11-enyl acetate	Ph	No	-	n.a.					X

follows on the next page →

ACTIVE INGREDIENT	TYPE	SYSTEMIC	IGR	LD_{50} HONEY BEE (µg/bee)		LD_{50} BOMBUS SPP. (µg/bee)	FOLIAR RESIDUAL TOXICITY (hours or days)	REGISTERED ON	
				LOWEST	ORAL	LOWEST		MELON	TOMATO
Tetradec-3,8-enyl acetate	Ph	No	-	n.a.					X
Tetradec-9-enyl acetate	Ph	No	-	n.a.					X
Tetradifon	A	No	No	60.4					X
Thiabendazole	F	Yes	-	>10				X	
Thiacloprid	I	Lim.	No	*17.3*				X	X
Thiamethoxam	I	Yes	No	0.005			7-14d	X	X
Thiophanate-methyl	F	Yes	-	>70				X	X
Triadimefon	F	Yes	-	25				X	
Triazophos	I, A, N	No	No	0.06					X
Trichlorfon	I	No	No	0.4			3-6h	X	X
Triflumizole	F	Yes	-	56.6				X	
Triflumuron	I	No	Yes	>100					X
Trifluralin	H	No	-	62.3					X
Triforine	F	Yes	-	>10				X	
Zeta-cypermethrin	I	No	No	*0.002*			>1d		X
Zoxamide	F	No	-	>153					X
(Z,Z,Z)-3,6,9-tricosatriene	Ph	No	No	n.a.					X

n.a = data not available; ? = possibly; n.i. = species not identified; - = no insecticide and therefore not applicable; Lim. = limited; d = day; h = hour; min = minute; mg = milligram; mL = millilitre; µL = microlitre
A=acaricide, I=insecticide, F=fungicide, H=herbicide, N=nematicide, PGR=plant growth regulator, Ph=pheromone, M=molluscicide, B=bactericide, R=rodenticide

ANNEX 3[1]
PESTICIDES REGISTERED AND USED ON THE FOCAL CROPS – KENYA

ACTIVE INGREDIENT	TYPE	SYSTEMIC	IGR	LD_{50} HONEY BEE		LD_{50} *BOMBUS* SPP. (µg/bee)	FOLIAR RESIDUAL TOXICITY (hours or days)	USED (AND REGISTERED) ON[2]			
				LOWEST	ORAL	LOWEST		COFFEE	CUCURBITS	FRENCH BEANS	TOMATO
Abamectin	I, A	Lim.	No	*0.002*			8-72h		X §	X	X
Acephate	I, A	No	No	0.36		3.69 (*B. terrestris*)	>72h		X §		
Acetamiprid	I	Yes	No	8.1	14.5	2.1 (*B. patagiatus*)			X	X	X
Alpha-cypermethrin	I	No	No	0.036		0.15 (*B. terrestris*)			X §	X	X
Azoxystrobin	F	Yes	-	>25				X	X §	X	X §
Bacillus thuringiensis (kurstaki)	I	No	No	>0.1							X
Beta-cyfluthrin	I	No	No	*0.001*					X §	X	X
Bifenthrin	I, A	No	No	0.013			>24h		X §		
Bronopol	B	No	-	n.a.							X
Carbendazim	F	Yes	-	>20					X §		
Carbofuran	I, N	Yes	No	0.15			>5d	X			
Carbosulfan	I	Yes	No	0.68			3.5d		X §	X §	X §
Chlorothalonil	F	No	-	181				X			
Chlorpyrifos	I	No	No	0.059		1.58 (*B. terrestris*)	4-6d	X	X	X	X
Copper hydroxide	F	No	-	>100				X			
Copper oxychloride	F, B	No	-	15				X		X	X
Cymoxanil	F	Yes	-	25	100				X	X	X
Cypermethrin	I	No	No	0.03			>3d		X §		X
Deltamethrin	I	No	No	0.017		0.6 (*B. terrestris*)	<4h		X	X	X
Diazinon	I	No	No	0.27			2d				X
Dimethoate	I, A	Yes	No	0.098		4.8 (*B. terrestris*)	3d	X §	X		X
Dithianon	F	No	-	100					X §		
Ethoprophos	I, N	No	No	*5.56*					X §		X §

follows on the next page →

1 ***Used pesticides*** : Farmer surveys (this study); ***Registered pesticides:*** Pest Control Product Board (PCPB) of Kenya [31]; ***Type,systemicity, IGR:*** Tomlin (2011) [37], Footprint PPDB (2011) [34]; ***Acute LD_{50} honey bee*** (oral or contact): FAO/OSU (2011) [33]. If missing in previous, Footprint PPDB (2011) [34] and Footprint BPDB (2011) [35] – *in italics in table*; ***Acute LD_{50} bumblebee:*** Mommaerts & Smagghe (2011) [36]; ***Foliar residual toxicity:*** Pacific Northwest Extension [88] & Florida Cooperative Extension Service [87]; determined for the honey bee at maximum normal US application rates.

ACTIVE INGREDIENT	TYPE	SYSTEMIC	IGR	LD_{50} HONEY BEE		LD_{50} *BOMBUS* SPP. (µg/bee)	FOLIAR RESIDUAL TOXICITY (hours or days)	USED (AND REGISTERED) ON[2]			
				LOWEST	ORAL	LOWEST		COFFEE	CUCURBITS	FRENCH BEANS	TOMATO
Fenitrothion	I	No	No	0.059				X	X §		X §
Glyphosate	H	Yes	-	>100				X	X §	X §	X
Imidacloprid	I	Yes	No	0.004		0.02 (*B. terrestris*)	>24h		X §		
Lambda-cyhalothrin	I	No	No	0.093		0.11 (*n.i.*)	>24h		X	X	X
Malathion	I	NO	No	0.47			5.5d	X §			
Mancozeb	F	No	-	>20					X	X	X
Metalaxyl	F	Yes	-	200					X §	X	X
Methomyl	I, A	Yes	No	0.42		0.57 (*B. terrestris*)	1.5d		X	X	X
Paraquat dichloride	H	No	-	26.8				X			
Pencycuron	F	No	-	>100					X §		
Propargite	A	No	No	15						X §	X §
Propineb	F	No	-	200					X	X	X
Spiroxamine	F	Lim.	-	4.21				X §			
Sulphur	F	No	-	1051					X	X	X
Tetradifon	A	No	No	60.4							X
Thiamethoxam	I	Yes	No	0.005			7-14d		X		X
Thiophanate -methyl	F	Yes	-	>70					X §	X	X §
Triadimefon	F	Yes	-	25					X §	X	X

2 If marked with §: the active ingredient is registered Kenya but not for use on the crop in question.
n.a = data not available; ? = possibly; n.i. = species not identified; - = no insecticide and therefore not applicable; Lim. = limited; d = day; h = hour; min = minute; mg = milligram; mL = millilitre; µL = microlitre
A=acaricide, I=insecticide, F=fungicide, H=herbicide, N=nematicide, PGR=plant growth regulator, Ph=pheromone, M=molluscicide, B=bactericide, R=rodenticide

ANNEX 4[1]
PESTICIDES USED ON THE FOCAL CROPS – THE NETHERLANDS

A. Tomato (greenhouse)

ACTIVE INGREDIENT	TYPE	SYSTEMIC	IGR	LD_{50} HONEY BEE (ug/bee)		LD_{50} *BOMBUS* SPP. (µg/bee)	FOLIAR RESIDUAL TOXICITY (hours or days)	
				LOWEST	ORAL	LOWEST		
Abamectin	I,A	Lim.	-	*0.002*			8-72h	
Acetamiprid	I	Yes	No	8.1	14.5	2.1 (*B. patagiatus*)		
Azaconazole	F	No	-	n.a.				
Azoxystrobin	F	Yes	-	>25				
Bacillus thuringiensis	I	No	No	*>0.1*				
Benzoic acid	I, F	No	No	n.a.				
Bifenazate	A	No	-	8.14				
Bitertanol	F	No	-	104				
Boscalid	F	Lim.	-	*100*				
Brodifacoum	R	No	-	n.a.				
Bromadiolone	R	No	-	n.a.				
Bupirimate	F	Yes	-	50				
Buprofezine	I	No	Yes	>200				
Carbendazim	F	Yes	-	>20				
Chlorothalonil	F	No	-	181				
Cyromazine	I	Yes	Yes	20			<2h	
Deltamethrin	I	No	No	0.017		0.6 (*B. terrestris*)	<4h	
Difenoconazole	F	Yes	-	101	187			
Difethialone	R	No	-	n.a.				
Ethephon	PGR	Yes	-	34.8				
Etridiazole	F	No	-	n.a.				
Fenarimol	F	Yes	-	100				
Fenbutatin oxide	A	No	-	100				
Fenhexamid	F	No	-	102				
Fenmedifam	H	No	-	23				
Formaldehyde	F	No	-	n.a.				
Glyphosate	H	Yes	-	>100				
Hexythiazox	A	No	-	>20				
Imazalil	F	Yes	-	39				
Imidacloprid	I	Yes	No	0.004		0.02 (*B. terrestris*)	>24h	
Indoxacarb	I	No	No	0.40				
Iprodione	F	No	-	400				
Potassium iodide	F	No	-	>0.78				

1 ***Used pesticides:*** CBS (2008) [32]; ***Type, systemicity, IGR:*** Tomlin (2011) [37], Footprint PPDB (2011) [34]; ***Acute LD_{50} honey bee*** (oral or contact): FAO/OSU (2011) [33]. If missing in previous, Footprint PPDB (2011) [34] and Footprint BPDB (2011) [35] – *in italics in table*; ***Acute LD_{50} bumblebee***: Mommaerts & Smagghe (2011) [36]

ACTIVE INGREDIENT	DISTRIBUTION OF PESTICIDE USE DURING THE YEAR (percent of total)											
		CONTINUOUS TOMATO FLOWERING PERIOD										
	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Abamectin	8	0	23	0	0	4	4	20	30	0	0	11
Acetamiprid	0	0	0	0	0	0	2	64	34	0	0	0
Azaconazole	0	100	0	0	0	0	0	0	0	0	0	0
Azoxystrobin	0	0	0	0	4	16	0	31	50	0	0	0
Bacillus thuringiensis	0	47	0	10	10	9	8	6	3	4	0	3
Benzoic acid	0	0	0	0	0	0	0	0	0	0	26	74
Bifenazate	0	0	0	0	63	15	7	13	2	0	0	0
Bitertanol	0	3	2	23	0	0	5	8	29	32	0	0
Boscalid	0	10	7	19	10	5	13	15	5	6	10	0
Brodifacoum	0	0	0	0	0	0	0	0	0	0	100	0
Bromadiolone	0	0	0	0	54	0	4	0	0	3	38	0
Bupirimate	0	0	36	0	0	25	8	8	8	8	0	7
Buprofezine	0	0	29	35	0	5	1	8	0	17	6	0
Carbendazim	0	22	22	15	19	23	0	0	0	0	0	0
Chlorothalonil	0	0	0	14	0	3	13	27	28	3	13	0
Cyromazine	5	0	0	9	28	16	24	0	17	0	0	0
Deltamethrin	0	0	0	0	0	0	0	1	21	78	0	0
Difenoconazole	0	0	0	100	0	0	0	0	0	0	0	0
Difethialone	0	32	0	0	0	37	0	0	0	0	30	1
Ethephon	0	0	0	0	2	0	42	4	3	18	15	17
Etridiazole	11	0	10	6	12	17	15	8	13	7	0	0
Fenarimol	0	0	0	0	0	0	0	100	0	0	0	0
Fenbutatin oxide	0	10	0	0	0	44	9	12	14	11	0	0
Fenhexamid	9	20	7	13	7	9	12	14	3	5	0	2
Fenmedifam	0	0	0	100	0	0	0	0	0	0	0	0
Formaldehyde	0	0	0	0	0	0	0	0	0	0	100	0
Glyphosate	0	0	0	0	13	10	4	61	11	0	0	0
Hexythiazox	0	18	0	0	0	18	5	25	35	0	0	0
Imazalil	13	1	0	0	9	25	17	10	6	19	0	0
Imidacloprid	0	0	0	0	0	0	47	0	0	53	0	0
Indoxacarb	1	0	0	88	0	0	2	2	2	3	2	0
Iprodione	9	5	1	47	4	7	6	1	7	7	7	0
Potassium iodide	0	0	6	10	14	10	27	3	11	19	0	0

follows on the next page →

ACTIVE INGREDIENT	TYPE	SYSTEMIC	IGR	LD_{50} HONEY BEE (ug/bee)		LD_{50} *BOMBUS* SPP. (µg/bee)	FOLIAR RESIDUAL TOXICITY (hours or days)	
				LOWEST	ORAL	LOWEST		
Potassium thiocynate	F	No	-	>1.0				
Lecanicillium muscarium VE6	I	No	No	*>110*				
Maneb	F	No	-	12				
MCPA	H	Yes	-	100				
Mecoprop P	H	Yes	-	>21				
Methomyl	I	Yes	No	0.42		0.57 (*B. terrestris*)	1.5d	
Methoxyfenozide	I	No	Yes	>100				
Paecylomyces fumosoroseus apopka 97	I, A	No	No	n.a.				
Peracetic acid	F	No	-	n.a.				
Piperonil butoxide	I	No	No	>10				
Primimicarb	I	Yes	No	6.21		8.5 (*B. terrestris*)	<2h	
Propamocarb	F	Yes	-	n.a.				
Propamocarb hydrochloride	F	Yes	-	100	116			
Pymetrozine	I	No	No	117			<2h	
Pyraclostrobin	F	Lim.	-	73				
Pyrethrins	I	No	No	0.053			<2h	
Pyridaben	I	No	No	0.024			<2h	
Pyrimethanil	F	No	-	>100				
Pyriproxifen	I	No	Yes	>100				
Spinosad	I	No	--	0.003			<2h	
Spiromesifen	I	No	Yes	*>200*				
Teflubenzuron	I	No	Yes	1000				
Thiacloprid	I	Lim.	No	*17.3*				
Thiophanate methyl	F	Yes	-	>70				
Thiram	F	No	-	74				
Tolylfluanide	F	No	-	92				
Trichoderma harzianum rifai T22	F	No	-	n.a.				
Triclopyr	H	Yes	-	100				
Triflumizole	F	Yes	-	56.6				
Verticillium lecanii	I	No	No	n.a.				
Hydrogen fluoride	F, B	No	-	n.a.				
Hydrogen peroxide	F, B	No	-	n.a.				
Sulphur	F	No	-	1051				

ACTIVE INGREDIENT	DISTRIBUTION OF PESTICIDE USE DURING THE YEAR (percent of total)											
		CONTINUOUS TOMATO FLOWERING PERIOD										
	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Potassium thiocynate	0	0	6	10	14	10	27	3	11	19	0	0
Lecanicillium muscarium VE6	0	0	0	0	0	0	0	5	5	1	89	0
Maneb	0	0	0	0	0	0	100	0	0	0	0	0
MCPA	0	0	0	0	33	33	0	0	33	0	0	0
Mecoprop P	0	0	0	0	33	33	0	0	33	0	0	0
Methomyl	0	0	0	0	0	0	0	0	0	26	52	22
Methoxyfenozide	5	0	8	38	11	3	4	10	4	3	15	0
Paecylomyces fumosoroseus apopka 97	0	0	0	0	0	0	0	0	0	0	0	100
Peracetic acid	0	0	0	0	0	0	0	0	0	0	0	100
Piperonil butoxide	0	0	0	0	0	0	0	40	60	0	0	0
Primimicarb	0	0	0	0	0	100	0	0	0	0	0	0
Propamocarb	0	16	16	16	0	0	23	30	0	0	0	0
Propamocarb hydrochloride	0	0	5	52	8	6	8	7	5	1	8	1
Pymetrozine	0	0	7	23	11	18	7	16	13	7	0	0
Pyraclostrobin	0	10	7	19	10	5	13	15	5	6	10	0
Pyrethrins	0	0	0	0	0	0	0	40	60	0	0	0
Pyridaben	0	0	0	0	35	0	0	0	16	16	17	17
Pyrimethanil	7	8	3	34	5	4	13	6	7	3	11	0
Pyriproxifen	11	0	6	20	13	5	12	8	14	0	11	0
Spinosad	0	0	0	0	12	12	29	16	14	16	0	0
Spiromesifen	10	21	0	0	0	0	0	20	11	12	24	1
Teflubenzuron	21	0	0	0	0	0	0	0	30	15	15	19
Thiacloprid	0	0	0	0	0	43	0	25	32	0	0	0
Thiophanate methyl	15	0	7	15	7	8	0	9	7	4	28	0
Thiram	27	2	7	0	0	0	28	22	14	0	0	0
Tolylfluanide	0	0	0	100	0	0	0	0	0	0	0	0
Trichoderma harzianum rifai T22	9	11	10	25	8	9	10	8	10	0	0	0
Triclopyr	0	0	0	0	100	0	0	0	0	0	0	0
Triflumizole	7	6	12	0	34	4	10	11	15	0	0	0
Verticillium lecanii	0	0	22	49	10	19	0	0	0	0	0	0
Hydrogen fluoride	0	0	0	0	0	0	0	0	0	0	100	0
Hydrogen peroxide	0	0	0	0	0	0	0	0	0	0	0	100
Sulphur	4	9	4	6	13	8	6	5	7	4	34	0

B – Apple

ACTIVE INGREDIENT	TYPE	SYSTEMIC	IGR	LD_{50} HONEY BEE (ug/bee)		LD_{50} *BOMBUS* SPP. (µg/bee)	FOLIAR RESIDUAL TOXICITY (hours or days)	
				LOWEST	ORAL	LOWEST		
1-naftyl acetic acid	PGR	Yes	-	*>120*				
2,4-D	H	Yes	-	97.4				
Acetamiprid	I	Yes	No	8.1	14.5	2.1 (*B. patagiatus*)		
Aluminium phosphide	I, R	No	No	*0.24*				
Amitrole	H	Yes	-	100				
Azadirachtine A	I	No	No	2.5			<2h	
Bacillus thuringiensis	I	No	No	*>0.1*				
Benzyladenine	PGR	?	-	n.a.				
Boscalid	F	Lim.	-	*100*				
Bromadiolone	R	No	-	n.a.				
Bupirimate	F	Yes	-	50				
Calcium hydroxide	F	No	-	n.a.				
Captan	F	No	-	26.4				
Codlemone	Ph.	No	-	85				
Cydia pomonella granulosis virus	I	No	No	n.a.				
Cyprodinil	F	Yes	-	316				
Deltamethrin	I	No	-	0.017		0.6 (*B. terrestris*)	<4h	
Dicamba	H	Yes	-	15.3				
Difenoconazole	F	Yes	-	101	187			
Diquat dibromide	H	No	-	27.8				
Dithianon	F	No	-	100				
Dodine	F	Yes	-	4.9				
Epoxiconazole	F	No	-	>100				
Ethephon	PGR	Yes	-	34.8				
Fenoxycarb	I	No	Yes	>100			24h	
Flonicamid	I	Yes	No	*>51000*				
Fluazifop-p-butyl	H	Yes	-	112	200			
Gibberillic acid A3	PGR	Yes	-	*>25*				
Gibberillin A4 A7	PGR	Yes	-	>25				
Glufosinate ammonium	H	Lim.	-	>100				
Glyphosate	H	Yes	-	>100				
Imidacloprid	I	Yes	No	0.004		0.02 (*B. terrestris*)	>24h	
Indoxacarb	I	No	No	0.40				
Copper oxychloride	F	No	-	15				
Kresoxim methyl	F	No	-	14				
Linuron	H	Yes	-	160				
Mancozeb	F	No	-	>20				
MCPA	H	Yes	-	100				
Mecoprop P	H	Yes	-	>21				
Metazachlor	H	No	-	>20				

	ACTIVE INGREDIENT	DISTRIBUTION OF PESTICIDE USE DURING THE YEAR (percent of total)							
		CONTROL OF APHIDS; HONEYDEW							
			All bees: flowering of apple & dandelion		**Bumblebees:** only nesting & not foraging in crop				
		JAN-MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT-DEC
	1-naftyl acetic acid	0	0	0	0	4	91	5	0
	2,4-D	0	48	15	24	13	1	0	0
	Acetamiprid	20	41	39	0	0	0	0	0
	Aluminium phosphide	0	0	0	0	100	0	0	0
	Amitrole	0	3	0	0	0	0	35	63
	Azadirachtine A	30	32	37	0	0	0	0	0
	Bacillus thuringiensis	48	52	0	0	0	0	0	0
	Benzyladenine	0	0	100	0	0	0	0	0
	Boscalid	0	0	0	0	33	32	35	0
	Bromadiolone	0	100	0	0	0	0	0	0
	Bupirimate	0	23	21	20	23	13	0	0
	Calcium hydroxide	0	0	0	0	0	0	0	100
	Captan	18	9	8	10	9	6	6	34
	Codlemone	0	0	100	0	0	0	0	0
	Cydia pomonella granulosis virus	0	0	0	25	29	46	0	0
	Cyprodinil	39	61	0	0	0	0	0	0
	Deltamethrin	0	35	18	34	13	0	0	0
	Dicamba	0	0	0	96	0	4	0	0
	Difenoconazole	1	27	18	18	20	0	0	16
	Diquat dibromide	0	0	53	0	0	47	0	0
	Dithianon	17	14	17	20	16	15	0	0
	Dodine	36	11	0	15	10	14	14	0
	Epoxiconazole	50	50	0	0	0	0	0	0
	Ethephon	0	0	18	8	12	25	20	17
	Fenoxycarb	0	37	28	18	17	0	0	0
	Flonicamid	14	17	17	7	22	22	0	0
	Fluazifop-p-butyl	0	0	0	37	0	63	0	0
	Gibberillic acid A3	0	0	100	0	0	0	0	0
	Gibberillin A4 A7	0	33	26	40	0	0	0	0
	Glufosinate ammonium	0	15	19	22	24	20	0	0
	Glyphosate	0	18	25	25	14	2	0	16
	Imidacloprid	25	18	24	14	1	0	0	17
	Indoxacarb	0	21	20	21	16	23	0	0
	Copper oxychloride	73	14	14	0	0	0	0	0
	Kresoxim methyl	15	24	29	31	0	0	0	0
	Linuron	0	0	7	53	40	0	0	0
	Mancozeb	38	62	0	0	0	0	0	0
	MCPA	0	0	15	17	21	33	0	14
	Mecoprop P	0	51	25	22	2	0	0	0
	Metazachlor	0	0	0	0	100	0	0	0

follows on the next page →

ACTIVE INGREDIENT	TYPE	SYSTEMIC	IGR	LD_{50} HONEY BEE (ug/bee)		LD_{50} *BOMBUS* SPP. (µg/bee)	FOLIAR RESIDUAL TOXICITY (hours or days)	
				LOWEST	ORAL	LOWEST		
Methoxyfenozide	I	No	Yes	>100				
Metiram	F	Yes	-	40				
Mineral oil	A, I	No	No	n.a.		500 (*n.i.*)		
Pirimicarb	I	Yes	No	6.21		8.5 (*B. terrestris*)	<2h	
Prohexadione calcium	PGR	Yes	-	100				
Pyraclostrobine	F	No	-	73.1				
Pyrimethanil	F	No	-	>100				
Spirodiclofen	I, A	No	Yes	*>196*				
Tebufenpyrad	A	No	No	3.29				
Thiacloprid	I	Lim.	No	*17.3*				
Thiophanate methyl	F	Yes	-	>70				
Thiram	F	No	-	74				
Tolylfluanid	F	No	-	92				
Triadimenol	F	Yes	-	*>200*				
Triclopyr	H	Yes	-	100				
Trifloxystrobine	F	No	-	>200				
Sulphur	F	No	-	1051				

	ACTIVE INGREDIENT	DISTRIBUTION OF PESTICIDE USE DURING THE YEAR (percent of total)							
		CONTROL OF APHIDS; HONEYDEW							
			All bees: flowering of apple & dandelion		**Bumblebees:** only nesting & not foraging in crop				
		JAN-MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT-DEC
	Methoxyfenozide	0	23	19	30	29	0	0	0
	Metiram	0	13	18	9	8	52	0	0
	Mineral oil	84	13	0	3	0	0	0	0
	Pirimicarb	0	14	15	18	16	26	0	11
	Prohexadione calcium	0	48	25	15	12	0	0	0
	Pyraclostrobine	0	0	0	0	33	32	35	0
	Pyrimethanil	33	31	36	0	0	0	0	0
	Spirodiclofen	0	0	40	35	25	0	0	0
	Tebufenpyrad	0	0	0	100	0	0	0	0
	Thiacloprid	34	34	32	0	0	0	0	0
	Thiophanate methyl	0	0	0	0	0	0	0	100
	Thiram	0	0	38	37	25	0	0	0
	Tolylfluanid	0	0	50	0	50	0	0	0
	Triadimenol	0	21	21	19	18	22	0	0
	Triclopyr	0	100	0	0	0	0	0	0
	Trifloxystrobine	0	19	25	26	29	0	0	0
	Sulphur	12	13	11	19	25	21	0	0

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Globally, agricultural production systems are under pressure to meet multiple challenges: to sustain or increase production from the same area of land and reduce negative impacts on the environment amid uncertainties resulting from climate change. As farming systems adapt to meet these challenges, one of agriculture's greatest assets in meeting them is nature itself. Many of the ecosystem services provided by nature – such as pollination – directly contribute to agricultural production. Beneficial insects such as pollinators may be heavily impacted by pesticides. This document makes a contribution to understanding the context of pesticide exposure of key crop pollinators – honey bees, but also wild bee species – through the development of risk profiles for cropping systems in Brazil, Kenya and the Netherlands. Risk profiles such as those showcased here can provide a qualitative evaluation of pesticide risks to bees in specific settings, and can be used to compare risks between different settings, facilitate discussion amongst stakeholders, identify gaps in information, set priorities for research, and establish priorities for risk mitigation.

GLOBAL ACTION ON **POLLINATION SERVICES**
FOR **SUSTAINABLE AGRICULTURE**

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